

**REPORT OF
DEPARTMENT OF DEFENSE
ADVISORY GROUP ON ELECTRON DEVICES
WORKING GROUP C (ELECTRO-OPTICS)**

**SPECIAL TECHNOLOGY AREA REVIEW
ON
DISPLAYS**

March 2004

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SECURITY REVIEW
DEPARTMENT OF DEFENSE

THIS REPORT IS A PUBLICATION OF THE DEFENSE ADVISORY GROUP ON ELECTRON DEVICES (AGED). THE AGED IS A FEDERAL ADVISORY COMMITTEE ESTABLISHED TO PROVIDE INDEPENDENT ADVICE TO THE OFFICE OF THE DIRECTOR OF DEFENSE RESEARCH AND ENGINEERING. STATEMENTS, OPINIONS, RECOMMENDATIONS, AND CONCLUSIONS IN THIS REPORT DO NOT NECESSARILY REPRESENT THE OFFICIAL POSITION OF THE DEPARTMENT OF DEFENSE.

ADDENDUM

Significant developments since the STAR workshop conducted in April 2002 are noted in this addendum.

U.S. Army Flexible Display Initiative

The US Army has initiated a flexible displays program. Within the Army's Flexible Display Initiative (FDI) the Army is creating and sponsoring a university led center at Arizona State University to develop flexible display science and technology solutions for the Army Transformation. The Army's Flexible Display Center (FDC) is the largest component of the of the Army's FDI. The FDI includes the FDC, development work at the US Army Research, Development and Engineering Command (RDECOM) headquartered at Ft Belvoir VA, and sponsored research, and congressional interest programs. The RDECOM development work includes the internal materials and device research at ARL in Adelphi MD and the system development and testing at the US Army Soldier Systems Center in Natick MA, the Communication-Electronics Research Development and Engineering Center (CERDEC) Night Vision and Electronic Sensors Directorate (NVESD) at Ft Belvoir VA, and the CERDEC Command and Control Directorate (C2D) at Ft Monmouth NJ.

The intent of the center is to establish a core capability to address the science and technology for the development of flexible displays in a pre-competitive environment. The center will establish a university-industry-government collaboration to find solutions to the critical challenges for flexible display development and manufacturing. Because this technology has significant dual-use potential, industry participants will have the opportunity to invest dollars and provide personnel to the center; industrial companies would have levels of engagement in the center based on the level of individual co-investment. The center will be structured to offer free sharing of information obtained in the cooperative environment while appropriately protecting industry-specific intellectual property in the technical areas that include substrates and barrier coatings, backplane electronics, electro-optic devices, packaging and testing, and production/manufacturing.

The FDI is intended to develop displays in limited quantities and provide demonstrator displays to the Army Program Managers and their system integrators. As part of the Manufacturing Technology (MANTECH) portion of the program, the FDI has received critical endorsements from the Army Program Managers. The FDC is also intended to supply limited quantities of displays to Army systems in the event that industry no longer produces displays needed for Army platforms.

U.S. Air Force Flexible Displays and Integrated Communications Devices (FDICD) Technology

The Air Force has awarded a Congressional interest program to develop wearable on-the-move information visualization options for the Air Force Special Operations Command dismounted Combat Controllers and for the combat pilots with whom they team to achieve precision battlefield effects. The goal is to develop flexible display and integrated communications device (FDICD) technology with leading edge global positioning, communications components, voice messaging, displays, and related technologies. The effort will (a) formulate and develop a technology concept that extends the capability of special tactics/special forces units that operate on the ground in forward areas of battle in their role supporting close air support, air traffic control, and target identification/designation; (b) analyze and identify critical functions and their deployment priority using a series of proof-of-principle experimental systems; (c) fabricate breadboard components and commence validation in a laboratory environment. A spiral develop strategy will involve both rollable display units for collaborative big screen tasks and wrist watch computers for individual tasks, both with integrated comm-nav-processing capabilities, for battlefield air operations (BAO) kits for AF combat controllers and global warfighter information systems (GWIS) for AF/Navy/Marine combat pilots.

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FOREWORD

Periodically, the Advisory Group on Electron Devices (AGED) conducts Special Technology Area Reviews (STARs) to better evaluate the status of an electron device technology for defense applications. STARs strive to elicit the applicable military requirements for a particular technology or approach while relating the present technology status to those requirements. The STAR culminates in a report that provides a set of findings and recommendations which the Office of the Secretary of Defense can utilize for strategic planning. The content of each STAR is tailored to extract the appropriate data through preparation of "Terms of Reference."

This STAR on Displays was conducted on 16-18 April 2002 at Systems Planning Corporation in Arlington VA. The objective was to gather information that would allow AGED to assist the Department of Defense (DoD) in defining a defense-wide science and technology (S&T) strategy for displays. Information obtained focused on (a) the potential of advances in display technology to drive revolutions in military affairs; (b) particular improvements in display technology needed for advanced applications; and (c) the technology performance trends amongst three grades of displays—consumer, ruggedized, and custom. The STAR also sought to define the likely evolution of non-military display technology in order to identify military S&T investment opportunities where war-fighting advantage is foreseen, and to identify the contributions of past defense display S&T investments in current systems. An assessment of the actual pace of technology creation and transition to warfighters was a general goal. This report documents the findings of that STAR including a review of the technology and assessment of the use and potential future use of display components and systems in DoD platforms.

Presentations were made by a distinguished group of 28 experts from industry, academia, and government. The plenary session provided an opportunity to hear the views of Ms. Carolyn Hanna, a professional staff member of the Senate Armed Services Committee, and Dr. Aris Silzars, President of the Society for Information Display (SID). Five focus sessions were held on commercial markets and trends, combat system prime contractors, display component manufacturers, display subsystem integrators, and research institutions. A government-only session was held on the third day. Several equipment demonstrations were made available at this STAR, including the Raytheon 32-in. digital display systems based on the TI digital micro-mirror device (DMD) for C4ISR applications, the IBM 9.2 megapixel 22-in. diagonal active matrix liquid crystal display (AMLCD) monitor for data visualization, the eMagin miniature active matrix organic light emitting diode (AMOLED) for helmets, the low power E Ink active matrix electrophoretic ink display (AMEPID), the Northrup-Grumman software tool for display acquisition, and avionics-grade AMLCDs up to 14-in from APC, Honeywell, and Rockwell for cockpits.

On behalf of AGED Working Group C, I express my sincere appreciation to all of the people who took part in this study—listed on the next page—for their valuable contributions. This applies particularly to Dr. Susan Turnbach, ODDR&E/S&T, whose encouragement, support, and tenacity were essential for the successful completion of this effort. I also extend my thanks to Dr. Darrel Hopper, Chair of this Displays STAR, from the Air Force Research Laboratory, for proposing this STAR topic and doing so much to assure a successful meeting and report.

Dr. Andrew Yang
Chairman, Working Group C (Electro-Optics)
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EXECUTIVE SUMMARY

Displays are critical devices in all weapons systems. Sensors and information systems enable warfighters to detect, locate, identify, and track targets, assure accurate real-time battlespace situational awareness, and provide an accurate battlefield damage assessment—but only if there is a display at the location of each and every friendly combatant. Display devices may be classified both as integrated circuit devices and as electro-optic devices based on the technical challenges found at the materials and fabrication levels. Display technology is inherently multi-disciplinary involving mathematics, chemistry, physics, human factors, and several engineering fields including systems, electrical and electronic, mechanical, communications, industrial, computer and software (for control and image rendering), and systems. Furthermore, displays involve a simultaneous S&T consideration of device features and structures at the macro-, meso-, micro-, and nano-scales and of time at peta-second to atto-second scales. Display research spawns whole new fields as a result of its multidisciplinary nature; for examples, the cathode ray tube enabled radar and television and the first commercially successful micro-electro-mechanical system (MEMS) was a high definition digital display system device. Display technology is vital to all six Quadrennial Defense Review Transformational Operational Goals and offers advanced technology solutions to the problems of accurate real-time situational awareness, identification, precision targeting, and timely informed decision-making. The continued development of high-performance, man-in-the-loop, and autonomous systems using advanced display technology is absolutely necessary to revolutionary improvements in defense capabilities for global surveillance and communications, special operations, precision strike missions against fixed and mobile targets, advanced antisubmarine warfare capabilities, and space and sea control systems. Display technology is also needed in Homeland Security because the applications there have human-information interfaces like those in DoD.

AGED makes four recommendations regarding display access, planning, investment, and transition:

- DoD should take steps to mitigate the risk of its current, near absolute reliance on off-shore sources of displays;
- DoD should establish a more rigorous mechanism to manage and coordinate available investments in displays;
- DoD should invest \$100M/yr in display areas where military advantage is foreseen and payoff is timely;
- Services should fund engineering development, manufacturing technology to rapidly leverage new products.

The DoD display S&T program must address problems facing warfighters that the commercial world will not. These problems include those associated with ruggedizing commercial products and using commercial manufacturing facilities for custom runs to gain special performance (e.g. in avionics displays). However, these problems go much farther into revolutionary technologies that the civil world considers too risky for private investment to support. Displays are a critical element in many electronic systems, serving as the human-machine interface that can faithfully transmit all the information available in a visually rich manner. A number of opportunities exist for DoD to advance display technology and provide the warfighter with improved knowledge and survivability. Areas where defense advantage is foreseen, but that will not be driven by commercial R&D, include virtual image head-up/mounted displays, 25 megapixel displays and 300 megapixel systems, flexible roll-up displays, artifact-free true-3D display systems, low weight and bulk wearable displays, and intelligent displays that eventually include all the functionality of the electronics now packaged separately in a computer case.

The DoD S&T investment strategy for displays must address a very wide range of system requirements. At one extreme are large, ultrahigh-definition, direct-view flat panel and projection color displays for use by warfighters in training systems and by combatant commanders for C4IRS battlespace force management. At the other extreme are the miniature, low-power, low-weight, direct-view flat panel and head-mounted devices (including night vision goggles) for individual mobile warfighter applications. The DoD goal of maintaining informational superiority and situational dominance while reducing the forward combat footprint requires a continual closing of the 1,000X gap between presently fielded warfighter interfaces (no display at all for most, or less than 1 megapixel in platforms) and the capacity of the human visual system (estimated as 1 gigapixel at 48 bits per pixel running at 80 Hz for a person). Current technical goals include development of high-fidelity (20:20 Snellian acuity) projectors providing 5,120 x 4,096 pixels compared to the 1,600 x 1,200 pixels now available, true 3D systems to enable intuitive understanding of spatial relationships in medical and battle control applications, flexible and transparent display enabling technologies, and integrated battlefield air operations (BAO) kits for special forces. State-of-the-art optics (diffractive, aspherics, hybrids, etc.), sensors (charged coupled device CCD focal plane array FPA, image intensifier tube I²T, etc.), and displays need to be investigated and integrated for future high-resolution direct-view, virtual image helmet-mounted and novel day/night applications in cockpits, command centers, and wearable systems. Concurrent development of sensor readouts and display driver electronic architectures need to be used to optimize power and bandwidth. All solid-state systems are needed to integrate all soldiers, sailors and aviators into the digital battlespace.

Much of the government funding for display research is in congressional special interest programs. These adds have, in aggregate, amounted to more than doubling the budget for DoD display S&T for many years. For example, some \$27 M display S&T funding was added in the National Defense Appropriations Act for Fiscal Year 2003 to the \$21M proposed by the services in the corresponding Presidents' Budget Request (PBR) for a total program of \$48M. This aggregate amount is down from about \$100M/year which prevailed prior to the cessation of DARPA program in FY01. Since the STAR meeting, the US Army decided to initiate a flexible displays program of > \$54M over FY04-FY09 for Objective Force (both Future Combat Systems and Objective Force Warrior); this initiative will address many of the concerns in the findings. The US Navy received adds but has dropped its planned program. The US Air Force received no add for displays but continues planned investments of some \$10M per year, which now includes displays for BAO, which was declared "A National Priority" in January 2003.

The recommendation of this report is that DoD raise its investment to at least \$100M per year for display S&T. This investment level can significantly influence the \$1.5B to \$5B per year invested in high-end research by the global display industry. This global industry is \$150B per year, which includes \$50B for display components. The US is the world leader in display S&T and display integration into civil and military products. The Asian countries are the leaders in affordable display manufacturing. Companies in Korea, Japan, and Taiwan have invested in dozens of the high-capitalization fabrication facilities (\$1B each) needed for active matrix display cells and modules. However, these modules are but one step in a long sequence required to deliver a product to a customer. Infrastructure for display materials and equipment exist in the US and Europe as well as in Asia. Thus, display manufacturing overseas is not a concern as long as US companies have reliable access to multiple sources. If the US is to continue to maintain its intellectual property (IP) leverage on the world display industry, a relatively modest investment of at least \$100M S&T per year is sufficient because of the extraordinary creativity of U.S. science. Asian facilities are driven by American innovation and IP. DoD can and must influence the display industry to maintain technological superiority on the battlefield.

"I want wearable and flexible rollout displays with integrated communications for battlefield air operations (BAO) in harsh austere environments."

-- SSGT Alan Yoshida, Combat Controller, USAF 720th Special Tactics Group

"I'd like my Dick Tracey watch." -- LGEN Paul V. Hester, Commander, USAFSOC

TERMS OF REFERENCE

DoD SPECIAL TECHNOLOGY AREA REVIEW (STAR) ON DISPLAYS

Approved 29 November 2001 by DoD Advisory Group on Electron Devices

PRIMARY OBJECTIVE:

The objective of this STAR is to provide information that will allow the Advisory Group on Electron Devices (AGED) to assist the Department of Defense (DoD) in defining and pursuing a defense-wide science and technology (S&T) strategy for displays.

Information sought bears on (a) the potential of advances in display technology to drive revolutions in military affairs; (b) particular improvements in display technology needed for advanced applications; and (c) the technology performance trends amongst consumer, ruggedized, and custom grades of displays.

SUPPORTING OBJECTIVES:

1. To define the likely evolution of non-military display technology in order to identify military S&T investment opportunities where warfighting advantage is foreseen.
2. To identify the contributions of past defense display S&T investments (over \$1B FY89-FY01) to current systems. To assess the actual pace of technology creation and transition to weapons.

ADDITIONAL QUESTIONS AND ISSUES TO BE ADDRESSED:

1. What improvements to display technology would be the most advantageous to your program? How would displays change doctrine (the way warfighters operate)? How would display technology improvements create/enable a revolution in military affairs (RMA)?
2. What roles, if any, should the DoD S&T community undertake in electronic displays:
 - (a) maintain an awareness of the needs and experiences of operational warfighters;
 - (b) monitor worldwide commercial and academic developments not funded by DoD;
 - (c) consult on acquisitions for systems program offices, logistics centers, and depots;
 - (d) invest in intramural programs (performed in government laboratories);
 - (e) invest in extramural programs (performed in academia & industry via contracting);
 - (f) other.

Describe the investment level (in person years, program dollars) appropriate in each of these six S&T activity areas. Answers may range from zero (no valid DoD S&T role exists) & up.

3. If the answer to Question 2 is greater than zero, what needs exist in displays that merit consideration for DoD S&T investment? What specific needs exist? Please categorize by time frame as follows:
 - (a) Near Term. Payoff expected within 5 years via transition of the results of the S&T project to an acquisition program (either new system, upgrade, or operational logistics support);
 - (b) Mid-Term. Transition anticipated in 5-10 years via planned demonstration program, such as those being formulated by the Army for Future Combat Systems, by the Navy for Future Naval Capabilities, and the Air Force for Global Reconnaissance Strike & Aerospace Dominance.
 - (c) Far-Term. Warfighting advantage anticipated in 10-25 years by enabling new systems not yet conceived or crew system interface equipment updates within current platforms.

4. Which acquisition strategy(ies) would you expect to employ in your system/subsystem builds? What is the dollar value of each option to your system? Is there another approach that is not listed?
- (a) straight COTS—purchase and send directly to weapon system operational unit;
 - (b) ruggedized COTS—value added by integrator to meet performance requirement;
 - (c) custom design produced in a consumer mass market manufacturing facility;
 - (d) other.

Will any custom designs continue to be necessary and, if so, in what defense applications.

5. How should DoD deal with displays issues on an ongoing basis? What is lacking or what are the shortfalls in current DoD S&T efforts/programs/activities relating to displays? What changes would you make, and what can industry do to assist in this process?
6. What should be the DoD display investment strategy given that most display manufacturing resides overseas? What are the appropriate ways of relating to foreign manufacturers? Is there concern if manufacturing continues to reside mostly outside of the US? Is the US realizing any economic benefit from licensing its developments, resulting from DoD S&T investments, to foreign manufacturers?
7. DoD has invested approximately \$1 billion in electronic display S&T over the past 13 years. What contributions has this past DoD S&T investment made to U.S. national defense? Please provide specific examples.

DEFINITIONS:

National Security Metrics:

- Life Cycle Cost (affordability over an electronics life cycle within a weapon system life cycle)
- Readiness (e.g. fleet availability rates, mission capable rates for systems and crews)
- Operational: reliability, maintainability, availability, and manufacturability
- User friendliness: warfighters actually use the displays and are delighted with their performance

Government Federal Acquisition Regulations (FAR) definition of COTS products:

“products of a type which are customarily used for non-governmental purposes
and which are offered for sale, lease, or license to the general public”

Commercial suppliers, however, do not generally distinguish a category of parts entitled COTS.

PARTICIPATION:

It is expected that the STAR will provide a forum for discussions between DoD and industry on displays. Military users and technology planners, who define warfighting capabilities, should be invited to participate as well as agencies responsible for procurement of major weapons systems and their required logistics support. Non-defense agencies such as DoE, DoC, DoT, NASA, and FAA, should be invited to attend, and, in some cases, present.

Two levels of participation are anticipated:

- (1) response to questions via mail/email/interview (plus RFI published in CBD)—all appropriate parties in government, academia, and industry interested in display S&T
- (2) briefing/discussion at two day workshop (16-17 April 2002)—subset of persons/institutions representative of defense S&T concerns

ANTICIPATED OUTCOME:

A detailed report that describes AGED's recommendations on the anticipated needs for display S&T investments in all facets of national security over three terms:

Near: < 5 years; Mid: 5 to 10 years; Far: > 10 years.

REFERENCES:

About AGED (public website): <http://aged.palisades.org>

Previous STAR on Flat Panel Displays conducted October 1992 (report published June 1994).

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AGENDA

AGENDA for AGED STAR on Displays

Day 1 – Tuesday 16 April 2002

Venue: SPC, 3601 Wilson Boulevard

*Located one block south of the Virginia Square Metro stop**

0730 Registration, Breakfast, Informal Discussion

PLENARY SESSION

0830 Introductions and Overview of STAR Objectives (Drs. A. Yang, S. Turnbach, D. Hopper)
0900 Congressional Perspective (Carolyn Hanna, Staff, U. S. Senate Armed Services Cmte.)
0930 Society for Information Display, President (Aris Silzars) – Future of Displays in the U.S.
1000 Break

Commercial Markets and Trends

1030 DisplaySearch (Mark Fihn) – Worldwide Commercial Display Market & Human Factors
1100 Intel (Mark Bunzel) – Advancements in Low Cost Visualization Systems Using COTS.
1130 Northrop Grumman (Al Calvo) – Display Acquisition Tools
1230 Lunch and Informal Discussion

Combat System Prime Contractors' Perspective

1330 Boeing (Arthur J. Behrens) – Boeing Display Process Action Team (DPAT) Initiative
1400 Lockheed Martin (Roy C. Brandenburg) – Naval UYQ-70 Workstations
1430 Exponent (John Geddes) and U.S. Army (SFC Chris Augustine) – Land Warrior Program
1500 Break

Display Component Manufacturers' Perspective

1530 American Panel Corp. (Jim Niemczyk) – Custom Military Displays in Commercial Fab.
1600 Kopin (Ollie Woodard) – COTS-based Miniature Displays for Military Applications
1630 E Ink Corporation (Pete Kazlas) – Paper-like Electronic Ink Displays
1700 Princeton University (Sigurd Wagner) – Steel and Plastic Display Science
1740 Adjourn for day (all but gov)

GvtOnly

1750 Kopin (Ollie Woodard) – Proprietary presentation
1820 Adjourn for day

* Take the Orange Line towards Vienna. Get off at the Virginia Square Metro station. You will come up the Metro escalator facing southwards. Walk ½ block south to SPC at One Virginia Square, 3601 Wilson Boulevard. Meeting facilities provided to AGED by DARPA.

AGENDA for AGED STAR on Displays

Day 2 – Wednesday 17 April 2002

Venue: SPC, 3601 Wilson Boulevard

Located one block south from the Virginia Square Metro stop

0730 Registration, Breakfast, Informal Discussion

Display Subsystem Integrators' Perspective

- 0830 Honeywell (Kalluri R. Sarma) – Avionic Display Systems (commercial, military, gen.av.)
- 0900 Kaiser Electronics (Mike Kalmanash) – Head-down, helmet displays in F-22, F-18, F-35
- 0930 Boeing (Carl Vorst) - Technology Challenges in Advanced Simulation Displays
- 1000 Break
- 1020 Rockwell Collins (Ray Liss) – Rockwell display programs
- 1040 US Displays Consortium (Ray Liss) – USDC Military Avionics Users Group
- 1100 General Dynamics (John Thomas) – Land & Sea Systems (Abrams, AAV, DD21, subs)
- 1130 Raytheon (Al Jackson) – Combat Workstations in AWACS Cabin and Shipboard CIC
- 1200 Lunch and Informal Discussion

Research Perspective

GvtOnly

- 1300 DARPA (Bob Tulis) – Summary High Definition/Flexible Displays Programs
- 1330 IBM Watson Res. Ctr. (Bob Wisnieff) – Ultra-Resolution Displays
- 1400 Sandia National Lab (Philip D. Heermann) – Massive Scientific Visualization
- 1430 Universal Display Corp (Julia Brown) – Organic Light Emitting Displays
- 1500 Break
- 1530 3DTL (Elizabeth Downing) – Approaches to True 3D displays & novel projector screens
- 1600 NASA Ames (Jim Larimer) – Architecture for Bandwidth Reduction (and human vision)
- 1630 Sytronics (Lee Task) – Human Factors and night vision
- 1700 eMagin (Web Howard) – Display Innovations—From Research to Products
- 1730 Adjourn

Day 3 – Wednesday 18 April 2002

*Venue: Palisades Institute, 1745 Jefferson Davis Hwy, Suite 500 ***

Located one block east of the Crystal City Metro stop

Attendance limited to AGED and government only on Day 3.

- 9-11:30 STAR report writing team meeting (in separate room from AGED Working Group C)
- 11:30-12:30 Lunch (joint with AGEDC)
- 12:30-14:30 AGEDC-report writing team discussion
- Discussion of 16-17 April 2002 STAR workshop presentations
- Outbrief from Displays STAR report writing team (working session during morning of 18 Apr)
- AGED Guidance to STAR report-writing team
- 14:30-15:00 Status of FY2002 update to displays roadmap

****** Take the Blue or Yellow line towards Reagan Wash. Natl Airport. Crystal City is the last metro stop before airport. Exit to street level; walk one block east to 1745 Jefferson Davis Hwy. (Alternative—go through the underground shops to underground elevator for 1745 JeffDavHy).

PRESENTATION SUMMARIES

APRIL 16-17, 2002 WORKSHOP

The complete briefings for these presentations are available at <http://aged.palisades.org> to qualified requesters. Summaries are included here based on initial text drafts prepared by the presenters in April 2002; eight missing text summaries were drafted by the STAR Chairman, Dr. Hopper, who then edited all summaries to achieve consistency of format and level of detail, and edited and inserted selected charts from the actual briefings. The edited summaries were sent to presenters for their approval, and all corrections they requested were made. The summaries are organized within this section as follows:

PLENARY

01. Introductions and Overview of STAR Objectives (Drs. A. Yang, S. Turnbach, D. Hopper)
02. Congressional Perspective (Carolyn Hanna, Staff, U. S. Senate Armed Services Cmte.)
03. Society for Information Display, President (Aris Silzars)-Future of Displays in the U.S.

COMMERCIAL MARKETS AND TRENDS

04. DisplaySearch (Mark Fihn, RossYoung) – Worldwide Commercial Display Market & Human Factors
05. Intel (Mark Bunzel) – Advancements in Low Cost Visualization Systems Using COTS.
06. Northrop Grumman (Al Calvo) – Display Acquisition Tools

COMBAT SYSTEM PRIME CONTRACTORS

07. Boeing (Arthur J. Behrens) – Boeing Display Process Action Team (DPAT) Initiative
08. Lockheed Martin (Kevin Greeley) – Lockheed Martin Aerospace Systems (presentation not given)
09. Lockheed Martin (Roy C. Brandenburg) – Naval UYQ-70 Workstations
10. Exponent (John Geddes) and U.S. Army (SFC Chris Augustine) – Land Warrior Program

DISPLAY COMPONENT MANUFACTURERS

11. American Panel Corp. (Jim Niemczyk) – Custom Military Displays in Commercial Fab.
12. Kopin (Ollie Woodard) – COTS-based Miniature Displays for Military Applications
13. E Ink Corporation (Pete Kazlas) – Paper-like Electronic Ink Displays
14. Universal Display Corp (Julia Brown) – Organic Light Emitting Displays

DISPLAY SUBSYSTEM INTEGRATORS

15. Honeywell (Kalluri R. Sarma) – Avionic Display Systems (commercial, military, gen.av.)
16. Kaiser Electronics (Mike Kalmanash) – Head-down, helmet displays in F-22, F-18, F-35
17. Boeing (Carl Vorst) – Technology Challenges in Advanced Simulation Displays
- 18a. US Displays Consortium (Raymond L. Liss) – USDC Military Avionics Users Group (MAUG)
- 18b. Rockwell Collins (Raymond L. Liss) – Rockwell display programs
19. General Dynamics (John Thomas) – Land & Sea Systems (Abrams, AAV, DD21, subs)
20. Raytheon (Al Jackson) – Combat Workstations in AWACS Cabin and Shipboard CIC

RESEARCH PERSPECTIVE

21. DARPA (Bob Tulis) – Summary High Definition/Flexible Displays Programs
22. IBM Watson Res. Ctr. (Bob Wisnieff) – Ultra-Resolution Displays
23. Sandia National Lab (Philip D. Heermann) – Massive Scientific Visualization
24. Princeton University (Sigurd Wagner) – Steel and Plastic Display Science
25. 3DTL (Elizabeth Downing) – Approaches to True 3D displays & novel projector screens
26. NASA Ames (Jim Larimer) – Architecture for Bandwidth Reduction (and human vision)
27. Sytronics (Lee Task) – Human Factors and night vision
28. eMagin (Web Howard) – Display Innovations–From Research to Products

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SUMMARY OF PLENARY PRESENTATIONS

01. *Dr. Andrew Yang (AGED), Dr. Susan Turnbach (OSD), Dr. Darrel Hopper (STAR Chair):
Introductions and Overview of STAR Objectives*

Dr. Yang, Chair of AGED Working Group C (Electro-Optics) welcomed everyone and outlined the purpose the workshop. Dr. Turnbach reviewed the nature of AGED and STARS, and indicated the rules for STAR reports. Dr. Hopper outlined the terms of reference and the agenda, and provided a visual definition of a display system as illustrated in Figure 01-07.

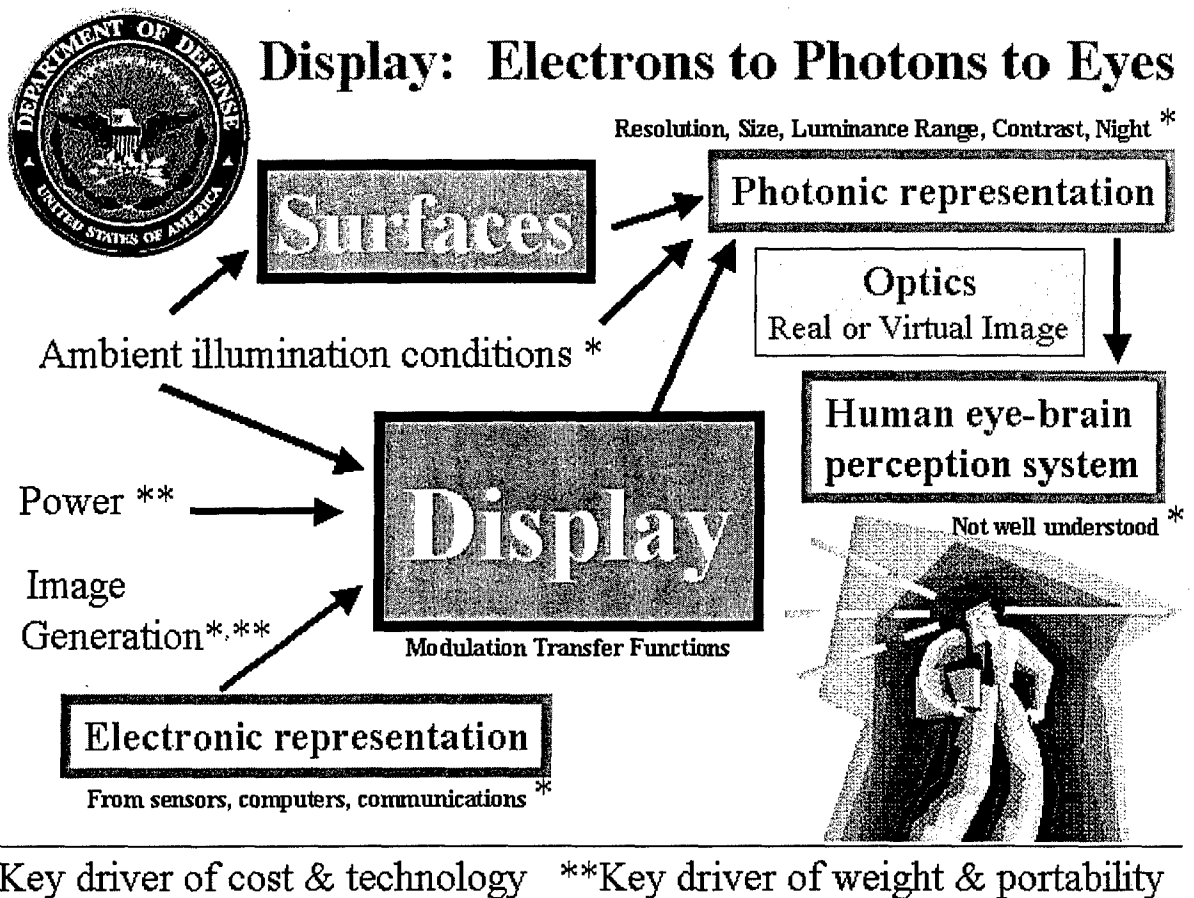


Figure 01-07. Display Systems as Transformers of Information Enabling Human Action.¹

¹ The real world 'display' system (RWDS) sampled at the limits of the human visual system (HVS) is estimated to be at least 1 Gpx x 48 bits/pixel x 80 Hz, which is equivalent to a RWDS information rate of 4 Tbps. Reference: Darrel G. Hopper, "1000 X difference between current displays and capability of human visual system: payoff potential for affordable defense systems," in *Cockpit Displays VII: Displays for Defense Applications*, Proc. SPIE 4022, 378-389 (2000).

02. *Carolyn Hanna (Professional Staff, Senate Armed Services Committee):
"Congressional Perspective"*

Ms. Hanna presented three general concerns of Congress—S&T, transition, people; then she addressed displays in detail. The primary general concern is basic funding for S&T and the need to hold the Services responsible for increasing it. Since S&T is basic to national defense and the economy, it "hits" every state and is an issue for all members. Per force, S&T becomes a vehicle for favors members need to place in the budget, or pork. Congress is always looking for new efforts that: (1) strengthen the nation's technology posture; (2) advise the Services and Agencies of needed changes in their future planned budget submissions; and (3) send dollars to every state. Ms. Hanna stated that Congress wants to see the military leveraging commercial technology, not subsidizing it. The Senate Armed Services Committee (SASC) believes that commercial technology is good and advancing quicker than military: kids video games provide faster 3D graphics. The SASC view is that our military equipment should be better (than commercial). Congress recognizes the need for additional funding to make this possible. Ms. Hanna stated that displays are important to many, many members of Congress.

Transition is another general Congressional concern. We need more effective mechanisms to transition S&T into warfighters' hands. Taking 10-20 years to put new capability out there is too slow. Afghanistan has been a showcase. The example cited was an Air Force interactive wall that has been fielded directly to the Central Command forward command post directly out of S&T, with a system development and refinement program following to produce improved configurations (spirals).

People is the third general Congressional concern. The challenge is how to get good people wanting to do defense S&T—in academia, industry and, especially, in government. The DoD civilian S&T population is going down rapidly; also, 50% will be eligible to retire within the next 10 years. We need to get young people interested in tough defense S&T problems. Displays S&T faces this problem.

As with S&T, advanced electronics needs to be a balanced portfolio (all interrelated, all part of a pie) to be effective. Displays are seen in every one of the experimental efforts in the Air Force, Army, and Navy. Warfighters must have the information they need get to them—to every one of them—while avoiding overload. You only want your warfighter to know what he needs to know—you do not want to overload him.

Ms. Hanna said members and staff need to be continually educated. They do not have time to go out for much information and rely heavily on inputs from the administration via its budget submissions, hearings, and reports, and from industry and academia via their visits, societies, and lobbyists. She held up ten binders of annual reports from the United States Displays Consortium (USDC) presenting an organized and unified message to the hill: "all you need to make decisions on display S&T needs." She characterized USDC as a wide advocacy group with several members in many states. Congress views the issues raised by USDC both ways: positive and negative. On the up side, wide Congressional membership is affected and annually write letters to defense committee members, ranking and chair, saying displays are critical. Some 25 members can be made happy with a plus-up for displays. One must keep in mind that it is easier to get funding (via PBR or Congressional add) if you have components being developed in every state. On the down side, in its oversight role, the Congress notes it has been getting the same message from industry every year: increase annual display S&T funding by \$25M. Congress asks, rhetorically, "Well DoD, what are you doing? We have told you year after year this (displays) is an important area, but still you refuse to invest (via your planned S&T budget submission). Displays are important to transformation. Someone in DoD needs to pull their weight. We keep adding and you keep lowballing us." The result is that the Congress views DoD management with cynicism and wishes to know why displays is underfunded. Roadmaps are critical in answering this and other questions, like "Is DoD relying on Congress for plusups?" and "Is DoD investing in defense-unique or leveraging industry?"

Both are good but how much is effective?" The administration always asks the Congress to leave the right amount of funding to them. Each spring the Congress then asks if the amount in the PBR for displays is appropriate—and the administration is silent; the next day USDC comes to Congress and says it is not. Lobbyists push SASC, HASC, SAC, and HAC for greater funding for displays. Annual reports by the USDC are found to be more credible by Congress than the low-ball position submitted each year to the Congress in the President's Budget Request (PBR). Thus, Congress adds substantially for displays to each years' PBR. Congress expects the administration to begin budgeting more funds in areas, such as displays, in which it adds substantial funds year after year.

Congress loves roadmaps. The displays roadmap is critical in helping Congress know where to expect increases in the PBR or, absent that, places where it can add. There is a need for a display roadmap from the military perspective. The electronics roadmaps are a wonderful way to provide a perspective on where the department wants to go. Ms. Hanna said she knows roadmaps are a bear and take years of work to put together. Congress will provide whatever help is needed to get them out the door and to the hill. Because the S&T area must be pursued on long-term basis (often 20 years to achieve investment payoffs), it is so much easier to understand S&T with a long term roadmap to point to. Congress needs to know we have so many years to get from here to there. Congress wants these roadmaps to include unfunded opportunities as well as funded programs; USDC and other lobbyists can carry the industry message the building (Pentagon agency) cannot carry and say "this is the unfunded piece, everything else depends on this piece." Congress will then call the building (Pentagon) and ask "is this true" and the typical no answer response will be taken to mean "yes, it is true."

Congress wants DoD to leverage the commercial market as much as it can. The rub is, are we leveraging or subsidizing? Leveraging is getting commercial technology into the military via ruggedizing and is frequently an excellent value. Congress does not wish to subsidize companies to make investments in S&T that they should be making 100% on their own for commercial markets, with DoD being one of many customers. One Congressional challenge is to percolate a vision of experimentation so the services will articulate the differences between their needs and what they have. These visions are driven by overarching concepts like combined fleet warfare (CFW), Future Combat Systems (FCS), Objective Force Warrior (OFW), and global effects-based warfare. There is not a whole lot out there in Nintendo land that can do it. Congress always wants military men in the field to have equipment better than now; much electronics equipment is > 14 years old.

Domestic capacity resonates on the hill. Congress provided \$100M for radhard electronics in FY02 to fund two plants. Congress wants to know where we are with domestic capacity for displays. In 1998 the House Armed Services Committee (HASC) defined two criteria for the ultimate success of the 1994 Flat Panel Display Initiative (FPDI): a domestic FPD industry and the proliferation of the use of FPDs in military systems. The latter criterion has been met; the former, not. If domestic capacity is still an issue, Congress wants to know what happened, where did we miss.

In terms of dollars, displays are typically but a small part of a weapon system. System issues are often much, much greater than display technology issues. The SASC finds it easy to spot groups that do not take into account other needs. Lots of work needs to go into the roadmaps and reports, including having the systems community mark them up so that they own them. However, it is up to the S&T community to say we have to have "x" to go forward to meet needs expressed by the systems community or to create advanced concept demonstrations to show to operators. Pull is nice, but push is an S&T responsibility too. Congress needs a way to incentivize program managers (PM of major weapon system) to innovate more with technologies that are ready to go; they now find new technology a career killer. The warfighter wants decision quality information. Congress often finds itself in a reactionary mode in doing business because its role is oversight; members and staff are dependent on folks just coming and informing them, and requesting reports from DoD when something falls off (goes wrong).

**03. Dr. Aris Silzars (President, Society for Information Display):
"The Future of Displays in the U.S."**

In the next decade, we can expect a proliferation of products incorporating displays inspired by the continuing rapid progress in compute power, image-processing software, and communications bandwidth. This will continue the accelerating trend which started over two decades ago as the use of electronic displays in non-television applications evolved from a few specialty products such as test instruments, military systems, and data terminals to become the primary human interface with computers and data communications devices. Because of forty years of television and instrumentation developments, in the 1980's displays were way ahead of what the new desktop computers needed. Today, we may be no better than at parity. At our present rate of progress, in another ten years displays will have become the highly visible bottleneck of the Internet Society.

The best that we can accomplish in bringing new display products to market in the next ten years has to a large degree already been set by what we know today about the basic materials and processes for creating emissive, transmissive, or reflective displays. How well we meet the needs of our colleagues in the rest of the high-technology community over the next decade will now depend on how much enthusiasm we can create in the investment community, within larger corporations, and within government agencies while being realistic in telling the world what rate of progress can be expected.

Over the next decade, some of the well-established display application areas such as television and personal computers will continue to be important to the display community. Other applications such as "wearable" electronics for commercial and military applications, specialized displays for automotive and military uses, internet appliances, advertising and public displays, and a plethora of toys and games will lead the way to the creation of totally new applications for display technologies. These applications will encourage the development of an ever-growing variety of display devices. These newer applications will prove to be excellent market entry points for new display technologies just as the laptop computer proved to be for high-information-content liquid crystal displays (LCDs).

The display technologies that we will have at our disposal either already exist today in their mature forms such as cathode ray tubes (CRTs) and LCDs, or in the early-stage basic materials technologies such as organic light emitting diodes (OLEDs) and field emission displays (FEDs). The mature technologies will continue to dominate the next decade. The newer technologies will typically find their first applications in new products that are yet to be developed. The proliferation of products and applications that use displays will drive a similar proliferation of display types and technologies. The new products such as next-generation PDAs and other Internet appliances will be the fertile ground that will allow new display technologies to be introduced.

The greatest successes in the U.S. market will be the result of strong international relationships that will facilitate the transition of innovative new technologies, first into specialty products used in relatively small volumes, eventually to be followed by the move to larger volume applications. This will be accomplished through business alliances with companies having excellent capability to develop cost-effective manufacturing processes. It is only through such international cooperation that it will be possible to meet the accelerating demands of the Internet Society for displays that are larger, smaller, brighter, more versatile, and lower in cost.

A comparison of the display market by technology type for 2001 (actual) and 2006 (projected) is provide in Figure 03-14.

MARKETS FOR DISPLAY TECHNOLOGIES

	2001	2006
• CRT	\$29,857	\$26,441
• LCD (Active)	16,801	41,841
• LCD (Passive)	5,456	5,757
• PDP	781	8,486
• OLED	29	1,258
• VFD	626	402
• LED	514	407
• MEMS	128	375
• EL	111	107
• FED	2	65

Figure 03-14. Markets for Display Technologies (\$M).

Dr. Silzars stated that government funding for basic display materials research is the best leverage of its research dollars by any measure. Most of the rest of the world (including Japan, Korea, and Taiwan) are followers, and are more adept at product and manufacturing process refinement than new technology innovation. They have traditionally relied on such innovation from the US. In the US, typically, basic materials developments that are started on government programs make things go—there is a really good history of this—with the only genuine breakthroughs being at the materials level. Furthermore, government programs can result in usable, buildable prototypes. Features like sunlight readability, higher color accuracy, wider gray-scale range, and new display architectures need attention but are being ignored by Pacific Rim manufacturers whose focus is driven by the consumer market (TV, PC, and games). DoD could drive these technology areas and combine them with existing techniques like tiling to create new capabilities like conformable displays, clothing active camouflage, and new electronics backplanes. Five-year efforts by the US government could reduce the risk sufficiently for these features to be adopted in the mainstream. However, the US does not have a robust infrastructure for manufacturing as do the Asian countries; the US must team with Asian companies for key display components, and for display product manufacturing as well, if it is desired to achieve prices for government programs approaching those of high-end consumer products.

"Most of the rest of the world are followers and rely on innovation from the US."
 -- Dr. Aris Silzars, President, international Society for Information Display (SID)

SUMMARY OF COMMERCIAL MARKETS AND TRENDS PRESENTATIONS

04. Mr. Mark Fihn, Mr. Ross Young (DisplaySearch): Worldwide Commercial Displays Market

Mr. Fihn's summarized display related trends for the commercial display market and a few challenges. The key theme was identified as flat panel displays (FPD²) and the applications enabled by them, including personal digital assistants (PDA) and mobile cell phones (CP), notebook (NB) personal computers (PC), LCD monitors, and advanced televisions (TV). Technology trends, supplier trends, and display performance trends were reviewed for each of these market segments. Particular attention was given to some of the issues associated with the adoption of improved displays in new everyday products that have, and will continue, to improve productivity and profoundly change the way people live.

The flat panel has become the dominant display technology type. Total sales of display modules for 2002 was some \$58B, comprising \$29.4B for FPD versus \$28.4B for CDTs/CPTs.³ As illustrated in Figure 04-11, the compound annual growth rate (CAGR) through 2007 for display modules is 8%, comprising 18% for FPDs and an 8% decline for CDTs/CPTs. The 2002 FPD revenue breakdown is 87.9% LCD⁴, 4.6% for microdisplays, 4.0% PDP, 2.5% VFD, 0.6% EL/FED, 0.4% OLED. Trends for FPD device technologies are forecast in Figure 04-14. Thin film transistor (TFT) or active matrix (AM) LCDs are the dominant segment accounting for a 76% share in 2002, up from 66% in 2001 on tremendous desktop monitor growth; an analysis for 8 AM FPD product application categories is provided in Figure 04-18.⁵

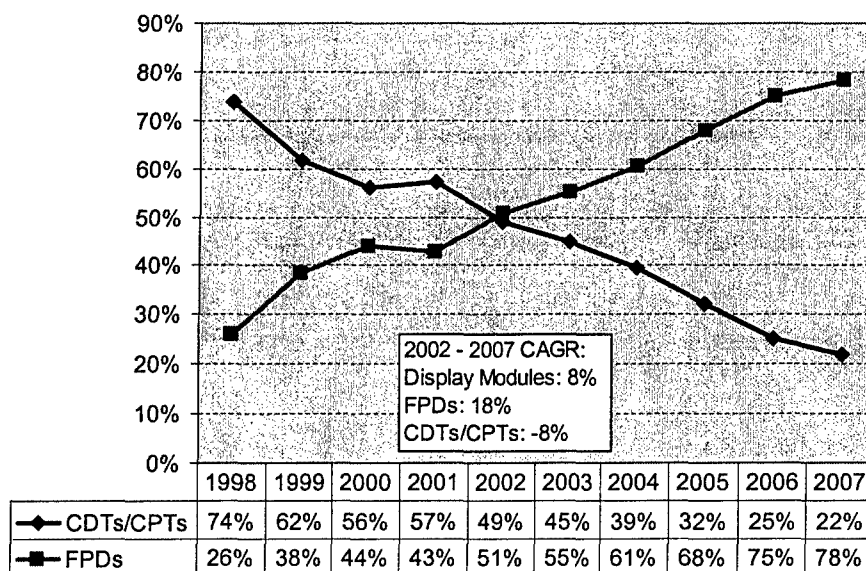


Figure 04-11. FPD Sales Surpassed CRT Sales in 2002.

² FPD devices include LCD, PDP, VFD, EL, LED, FED, VFD, OLED and a variety of microdisplays (uD, comprising uLCD, uOLED, DMD and other MEMS) (see glossary).

³ CDT = cathode display tubes (used in monitors) and CPT = cathode projection tubes (used in TVs).

⁴ LCD varieties: electronic drive backplanes are either passive matrix (PM) or active matrix (AM); LC structure is typically twisted neumatic (TN) for AM drive and super-twisted neumatic (STN) for PM drive; STN sub-varieties include monochrome (MSTN) and color (CSTN).

⁵ Active matrix is implemented with various devices, esp. the TFT transistor, but also others including MIM diode, with one or more devices in each sub-pixel.

	2001	2002	2002 Growth	2007	2002 - 2007 CAGR
TFT LCDs	14.6	22.2	52%	51.0	18%
PMLCDs	4.7	3.6	-23%	2.6	-7%
PDPs	0.7	1.2	71%	9.1	51%
AMOLEDs	0.0	0.0		1.6	185%
PMOLEDs	0.1	0.1	60%	0.5	36%
Microdisplays	1.2	1.4	14%	1.7	5%
Other	1.0	0.9	-7%	0.7	-5%
Total	22.2	29.4	32%	67.2	18%

Figure 04-14. FPD Revenues by Technology (\$US Billions).

	2001	2002	2002 Growth	2007	2002 - 2007 CAGR
Desktop Monitors	5.3	9.7	84%	20.9	17%
TVs	0.3	0.6	78%	14.0	89%
Mobile Phones/PDAs	0.7	1.5	116%	4.2	22%
Notebook PCs	5.4	6.8	27%	7.1	1%
Industrial	0.6	0.6	5%	1.1	11%
Cameras/Camcorders	0.6	0.8	24%	0.5	-7%
Automotive	0.5	0.6	12%	0.9	11%
Games/Toys/Pachinko	0.9	0.8	-7%	1.0	4%
Other	0.4	0.9	116%	1.3	8%
Total	14.6	22.2	52%	51.0	18%

Figure 04-18. AMLCD Revenues by Application (\$US Billions).

Fabrication of AM LCDs is capital intensive; generation-5 TFT LCD facilities cost \$1B each. The AM "backplanes" in AM FPDs are analogous to integrated circuit (IC) chips and wafers, but ones in which even one defect is noticeable and critically impacts yield. The CAGR for unyielded TFT LCD capacity is 37%, comprising 36% for a-Si and 46% for low temperature polysilicon (LTPS). A cyclic nature has been documented for AM TFT display manufacturing, the so-called *crystal cycle*, with over-investment in fabs and equipment during peak sales years, leading to over capacity and sharp price decreases. Mr. Fihn stated that the market is cyclical because it takes a long time to build a fabrication facility (fab) and TFT LCD suppliers must predict market conditions 18-27 months in advance even though conditions change more quickly. When fab capacity is added it is typically in large increments of 30K substrates per month.⁶ Monthly capacity for 15-in. TFT LCD panels (for notebooks, small TVs) has risen from 180K units at fab generation 3.5, to 450K units at generation 5 (first line opened in 2002), and will be 900K units at generation 6. Panel suppliers tend to add capacity at the same time and to wait to do so until prices are rising; actually, the best time to add capacity is when prices start falling sharply, as this event indicates demand and pricing will rebound by the time it comes on line. However, when prices and margins fall, panel suppliers tend to delay capital expenditures. The combination of rising demand and (ill-timed) slow capacity growth then causes a shortage. The size of cycles should shrink as more markets develop and magic price points are reached in price sensitive markets. The crystal cycle has a periodicity of about 3 years; oversupply conditions existed in 1998 and 2001 and are projected again in 2004; the

⁶ Generation 5 AMLCD substrate size is 1000 - 1200 x 1200 - 1300 mm; future generations to grow towards 1880 x 2150 mm; compared to current silicon IC fabs for which the substrate size is 300 mm.

industry has been in shortage in the first half of 2003. The AMLCD manufacturers in Japan and Korea have stated that, averaged over several cycles, they make a profit.

Mobile phone (MP) display shipments, including sub-displays in clamshell configurations, are expected to grow from 446M units in 2002 to 666M in 2007, an 8% CAGR. Display technology shipments for MPs in 2002 excluding sub-displays was 78% MSTN LCD, 12% AM LCD and 10% CSTN LCD; by 2007 the breakdown is projected as 43% AM LCD, 33% MSTN LCD and 17% CSTN LCD, and 7% OLED.

Notebook personal computer (NB PC) shipments are 100% AM TFT LCD. Total NB LCD shipments are expected to grow from about 30M units in 2002 (\$6.8B) to 53M units in 2007. The dominate size in 2002 was 14.1 in. (about 55%); over the next few years the average panel size is projected to grow towards 15 in. The dominant pixel format in 2002 was XGA (about 83%); the dominate resolution is expected to grow significantly by 2006 to UXGA (about 40% of 55M units). The SVGA and lower resolutions have virtually disappeared from commercial NB products. The average selling price of a NB PC (paid to LCD fab by NB PC manufacturer) has varied significantly over the years from \$494 in January 2000 to \$188 in September of 2001, \$272 in June of 2002 and fell to \$175 by the end of 2002. The NB TFT LCD market share is divided among many Asian companies as shown in Figure 04-38; Korean suppliers led with a 43% share followed by Taiwan headquartered companies at 30% and Japan companies at 26%.⁷

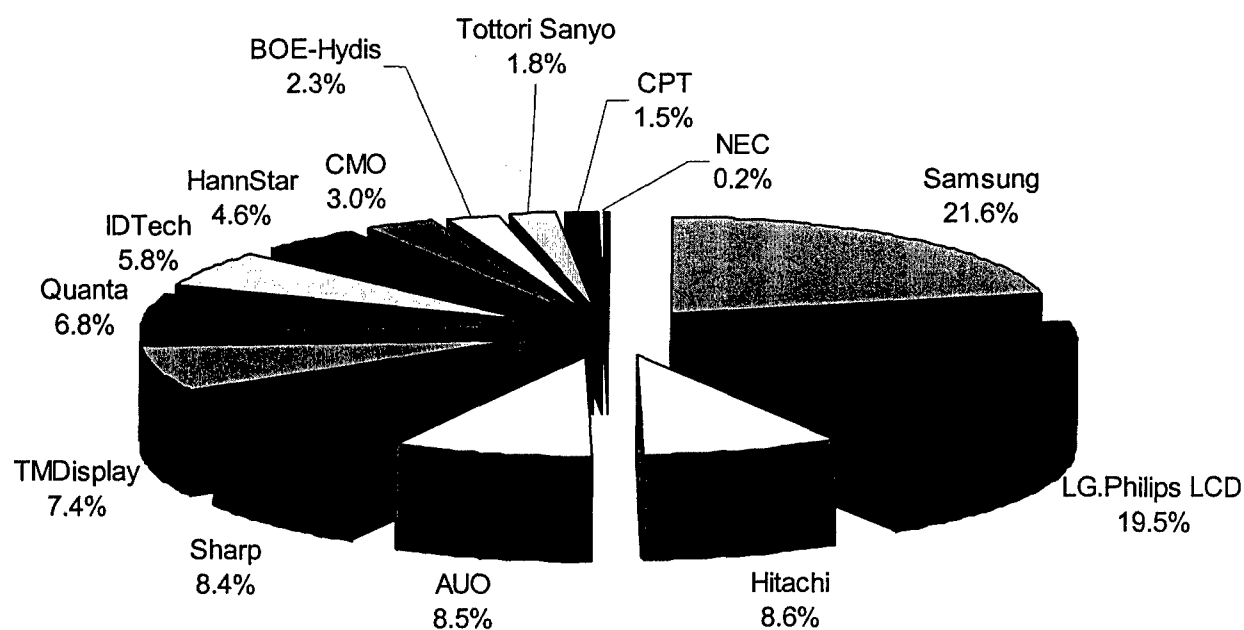


Figure 04-38. Q4 2002 Notebook Panel Share (Unit Basis).

⁷ In mid-2002 LG-Philips LCD began production in the world's first gen 5 facility, surpassing Samsung in capacity.

The move to China is on. Original equipment manufacturers (OEMs) for NBs are shifting to China and TFT LCD facilities are expected to follow.⁸ All major Taiwan notebook makers are setting up manufacturing operations in China; in 2002 an estimated 4M NBs were made by Taiwanese companies in China. Over 61% of all NBs are made by Taiwan OEMs but just 48% of the TFT LCDs are shipped to Taiwanese OEMs. Branded NB market share was led in Q1'03 by HP, Dell, Toshiba, and IBM with 8-16% share each

Future NBs will have larger sizes, higher resolutions, wide aspect ratios, wide viewing angles (they already have this), new concepts, and table PC form factors. In 1995 the conventional thinking was that no one would carry a NB PC with and LCD greater than 12.1 in. In 2002, Sony introduced a 16.1 in. UXGA TFT LCD in its VAIO NB series while Apple introduced a 17 in. 1440 x 900 pixel TFT LCD. Aspect ratios include 16:9 HDTV formats (1920 x 1080 and 1280 x 720), 3:2 DVD format (720 x 480), 17:11 paper format (two 8.5 x 11 in. pages), keyboard format (tablet PCs), and simpler column drive formats. Pixel densities range from 91 to 147 pixels per inch (ppi). Viewing angles for NBs and other AM TFT LCD products are now over 140° horizontal and 130° vertically by use of techniques like Sharp's Super-View, IBM's FlexView super in-plane switching (IPS), and Hitachi's antireflecting (AR) film. New concepts include screens that roll (Toshiba Rollable NB), rotate (Sony Rotating VAIO), swivel (Swivel Innovation swiveling NB), detach (Rever Detachable Display for plug-in to multiple platforms), morph (Compaq morphing NB-desktop PC). Wireless connection of components (display, computer, keyboard) is another trend.

The FPD monitor market is 100% AM TFT LCD and growing more rapidly than the NB market. In 2002 some 27% of all AM TFT LCD are used in desktop monitors; the 2007 projection is 76%. Total large-area (10in.+) AM TFT LCD shipments are projected to grow from 69M to 219M from 2002 to 2007 (unit CAGR 26%); revenue, from \$18B to \$43B (revenue CAGR 19%). Total monitor module revenues (CRT, LCD) of some \$17B (59% TFT LCD) in 2002 is projected to grow to \$23B (90% TFT LCD monitors) by 2007. The trend is to larger monitors; from 2002 to 2007, for example, the average diagonal will rise from 15.8 in. to 17.2 in. as the 17 in. LCD share rises from 21% to 52% and the 15 in. share falls from 69% to 23%.

Despite projected declines in TFT LCD equipment spending from 2004 – 2006 and a 14% TFT LCD surplus expected in 2006, 24 million 10in.+ LCD TVs are likely to ship that year due to significant average selling price (ASP) declines on lower panel costs resulting from lower depreciation and personnel costs inherent in larger substrate fabs. For example, DisplaySearch's fab modeling revealed that depreciation costs should fall by 66% from 680 x 880 mm to 1500 x 1800 mm fabs on a square meter basis fueling cost reductions. 30" LCD TV costs are projected to fall below \$1000 in 2006 with panel prices below \$500 enabling TVs to become the fastest growing FPD segment on a revenue basis with 73% CAGR expected from 2002 to 2007 and a 33% revenue share, up from just 5% in 2002. The FPD share of the TV market covering all sizes is expected to rise from 2% in 2002 to 22% in 2007 on a unit basis and from 6% to 58% on a revenue basis with the TFT LCD share expected to rise from 2% to 22% on a unit basis and 3% to 36% on a revenue basis. The barrier to AMLCD size was though a few years ago to be 20-30 in. but Samsung and LG.Philips LCD broke the 50" barrier in 2003. With the economics of large substrate fabs expected to result in significantly lower costs, DisplaySearch expects LCDs to become the dominant technology in the 30"+ TV market by 2007 as shown in Figure 04-63. PDP TV panels are also expected to enjoy rapid growth rising at a 76% CAGR to nearly 8 million panels also fueled by lower prices and anticipated improvements in performance. Meanwhile, projection TVs will also fight in this space and are expected to grow at a 12% CAGR to over 5 million units. Screen

⁸ Hyundai sold its TFT LCD subsidiary, Hydis, to a Chinese manufacturer in late 2002. The Hydis TFT LCD technology was developed in collaboration with ImageQuest, a Hyundai subsidiary that operated in Fremont CA in the mid-1990s. NEC also formed a joint venture with SVA.

technology must be optimized separately for RP and FP. One promising RP screen technology is the SCRAMscreen from SCRAM Technologies, comprising a polyplanar optic screen that expand the image vertically from a compact Schlieren optic light engine.

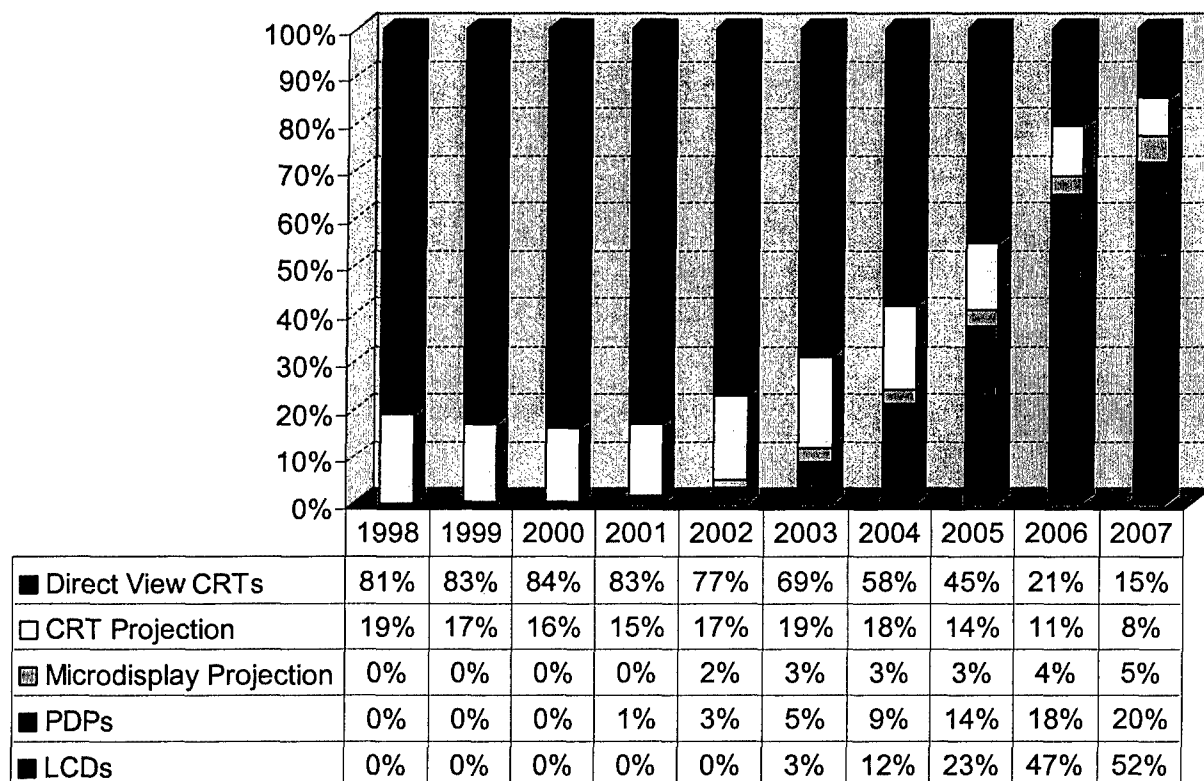


Figure 04-63. 30-inch TV Market Forecast By Technology.

Digital television (DTV) will create a demand for new displays capable of producing images that use the additional information to produce clearer and higher resolution images. There are 18 DTV standards, with some classified as high definition television (HDTV) and others, standard definition television (SDTV). Two HDTV standards are now being commercialized: HDTV-2 (720P signal, 1280x720 pixel format) and HDTV-4 (1080I signal, 1920 x 1080 pixel format). Two SDTV standards are also being commercialized, 480P (704 x 480 pixel format) and 480I (640 x 480 pixel format). One HDTV signal in 1080I or 720P standard is transmitted over a single 6 MHz channel (same size as current day analogue NTSC TV). Multiple SDTV signals (4-5) can be simultaneously transmitted of a single 6 MHz channel. The 6 MHz channel is the same size as currently used to transmit a single NTSC analogue signal. Each SDTV signal is about 4 times clearer than current NTSC signals; source camera imagery lost in NTSC transmission is not lost in SDTV transmission due to error correction enabled by digital signals. The reason for the multiple DTV standards is the multitude of cinematographic aspect ratios: Academy (1.37:1), 35 mm Spherical (1.85:1), 70 mm (2.21:1), Panavision (2.39:1), Cinemascope (2.55:1), Cinerama (2.59:1), and MGM Camera 65 (2.76:1). The HDTV aspect ratio of 16:9 (1.78:1) was picked as a compromise among the various movie formats. The current 4:3 (1.33:1) for current NTSC TV is close to the Academy movie format. The size to which TV screens may grow in the home market may be limited by room size: a 72 in. diagonal screen for HDTV 16:9 (SDTV 4:3) should be viewed at 10 ft. (17 ft.), if one accepts the optimum viewing distance recommendations for video viewing of 3.2 (7.2) times

screen height. That is, a room of a given size can accept a 16:9 screen almost twice as big in diagonal measure as a 4:3 screen. Wide aspect ratios are better suited for the human visual system and may drive higher adoption rates, especially in smaller homes. Designers of NB and FPD monitors should consider that larger panel sizes in wide aspect ration will appear rather small when viewed next to a panel in 4:3 aspect ratio.

Mr. Fihn raised several high-resolution issues. First, he noted that people prefer high resolution. There is a large base of suppliers and yields are high. Desirable improvements include software scalability (operating system, applications, webpages written for resolutions greater than SVGA, greater battery life and brightness, decreased weight and thickness, electromagnetic interference (EMI), and development of video controller electronics. The main problem is overcoming "I can't." A big advantage of higher LCD pixel density and screen resolution is reduced scrolling: an SVGA display requires five scroll-downs to get the equivalent of one screen of UXGA content; thus, high resolution reduces printing and on-line waits. Mr. Fihn also stated that the data pipeline between the processor and the display is a bottleneck to high resolution; there was much discussion on this topic during the session and two definitions were accepted—bandwidth from the computer to the display, and from the display to the pixels.

Lastly, Mr. Fihn noted that Hippocrates said "The chief virtue that language can have is clearness, and nothing detracts from it so much as the use of unfamiliar words." The displays area may be in danger of confusing it self with so many acronyms, formats, and arcane terms; simplification and education are needed.

During the Fihn presentation the following comment was made: Japan spends significantly more of its gross domestic product (GDP) on research and development (R&D). When the U.S. develops new display technology we transfer it out of the country for manufacturing so we can get lower cost displays—but they get the new products and profits and the U.S. does not see benefits of the expansion of the display industry, such as job growth opportunities and secure domestic sources.

05. Mr. Mark Bunzel (Intel): "Advancements in Low Cost Visualization Systems Using COTS"

Mr. Bunzel stated that display performance is behind the ability of the processor. Moore's Law⁹ set the stage over 30 years ago for the PC to begin to approach the capabilities of today's high performance visualization systems. Not only did Moore's law predict the growth in power, and the drop in costs of PCs, but it now can be applied to the continued advancements in graphics processors (GP) from such leading companies as NVIDEA and ATI. Visualization systems can build upon low cost consumer PCs and graphics systems now available for our teenagers at home to play the most advanced consumer simulation games.

"People prefer high resolution."
-- Mark Fihn and Ross Young, DisplaySearch

⁹ Moores' Law: The number of transistors on an integrated circuit (IC) chip doubles every 18 months. On 10 Feb 2003, Moore stated that process will slow to doubling every 24 months, but will go on through 2013.

While the low cost of a single PC and graphics system is compelling, it is still not enough power for today's visualization and simulation applications. But by aggregating a cluster of PCs, using the high speed digital video interface (DVI) standard for video output and a pixel switch or router, scaleable solutions can be quickly assembled that avoid many of the bottlenecks for visual throughput at reasonable costs. Present displays are not able to present all the information the processor cluster can provide.

Intel, together with Stanford University, worked to develop software and a prototype pixel router that allows the visualization task to be parsed and divided amongst a cluster of PCs and recombined for display on one or many screens. As a switch and frame buffer, the pixel router offers complete flexibility on resolution, frame rate and pixel addressability. The result is the emergence of a new class of visualization systems based on scaleable clusters of PCs equipped with the latest graphics processor technology together with a pixel router for the display. Performance can be scaled to rival today's high-end graphics systems but at a cost savings of 4X – 8X. The systems are modular and allow for easy upgrade when new graphics cards are introduced to the general public. These PC-based visualization systems form a highly flexible and easily upgradeable system which can be scaled to meet the future demanding visualization and simulation applications using commercial off the shelf (COTS) components. The cost savings can then be applied to further distribution of visualization and simulation platforms throughout an organization.

An illustration of how Visualization Clusters support new large display systems is illustrated in Figure 05-(03,06). Aggregation of multiple PCs at the video signal level bypasses the typical bottlenecks.

**06. Mr. Albert B. Calvo (Northrop Grumman Information Technology):
"Military Display Acquisition Support Tools"**

Mr. Calvo summarized the Acquisition Support Tools that Northrop Grumman Information Technology (formerly Litton TASC) has been developing for the military display community under the sponsorship of the United States Displays Consortium (USDC) co-funding from DARPA and industry. Two tools are currently under development

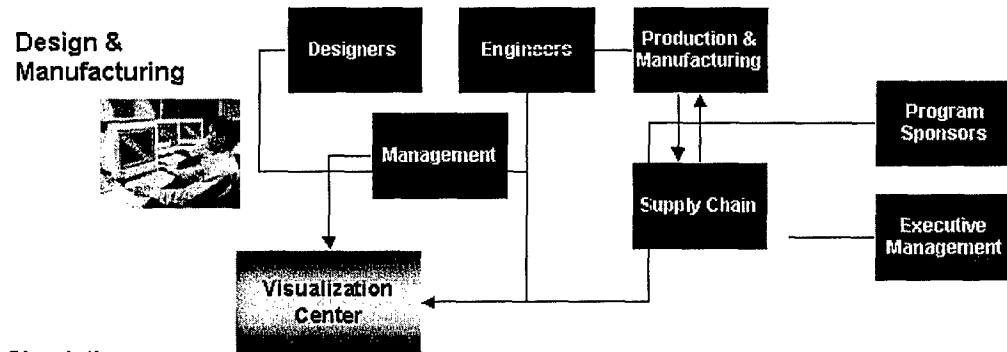
Web-LCCA: a web-based life cycle cost analysis tool for use in acquisition programs by government program offices and military display equipment suppliers;

DISPLA: a Decision Information System for Procurement and Logistics Analysis of military displays.

Web-LCCA is a model for predicting the life-cycle costs of military displays. The model is a derivative of TASC's LCCA™, which has been used in major military systems acquisition programs. It is designed to aid in the evaluation of different system designs and acquisition options. The intended users of Web-LCCA are display *suppliers* (Industry) and *buyers* (Government Program Offices). Web-LCCA is intended to be the standard tool for supporting cost tradeoffs and acquisition decisions among current operational displays and new flat panel display products. Version 2 of the model is currently available to the Display community, which models COTS and custom type displays. Northrup Grumman has plans for making this model accessible via the World Wide Web.

The Decision Information System for Procurement and Logistics Analysis (DISPLA) is a proof-of-concept information-exchange system for use by *buyers* (Government Program Offices and Weapon Systems Integrators) and by *sellers* (Display systems integrators and component suppliers) to aid in the acquisition of *affordable and sustainable military displays*. A proof-of-concept demonstration is presented using sample data from display suppliers Web sites and Government data sources. The overall architecture of the *DISPLA* system and its tiered search engine are illustrated above in Figure 06-(18,19).

Visualization Centers & Simulators too costly today...



Simulation



Today -- limited by requirement to travel to a Visualization or Simulation Center

Tomorrow -- lower costs for visualization & Sims allow deployment of this technology to broader audiences for collaboration & decision making

Simulator Images Courtesy: L3

Key: Scalable Architecture for input and output

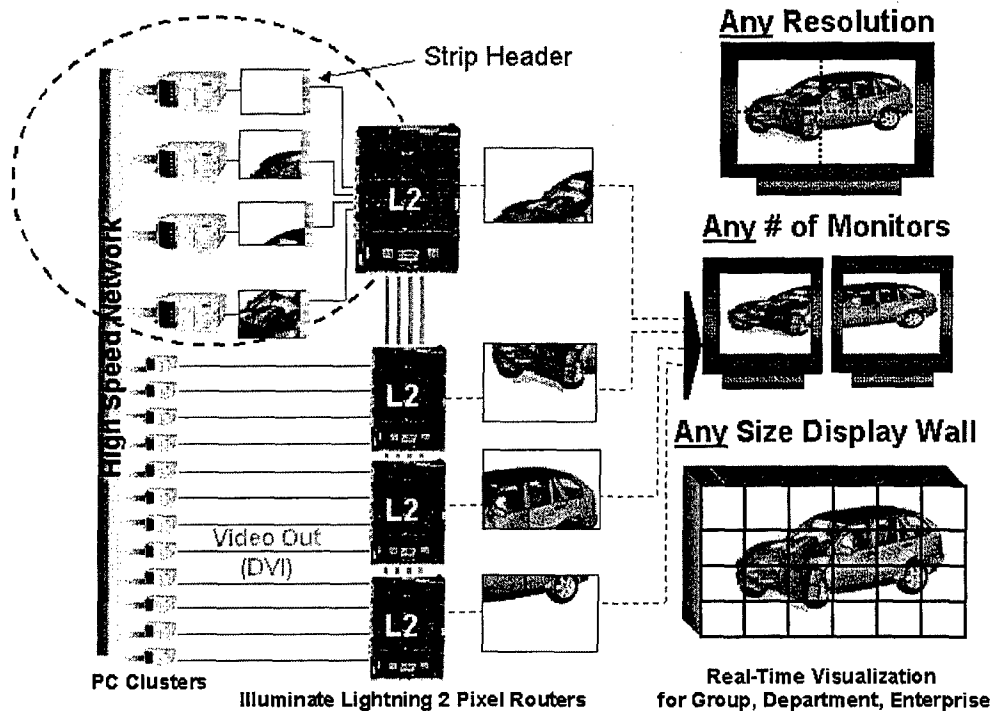
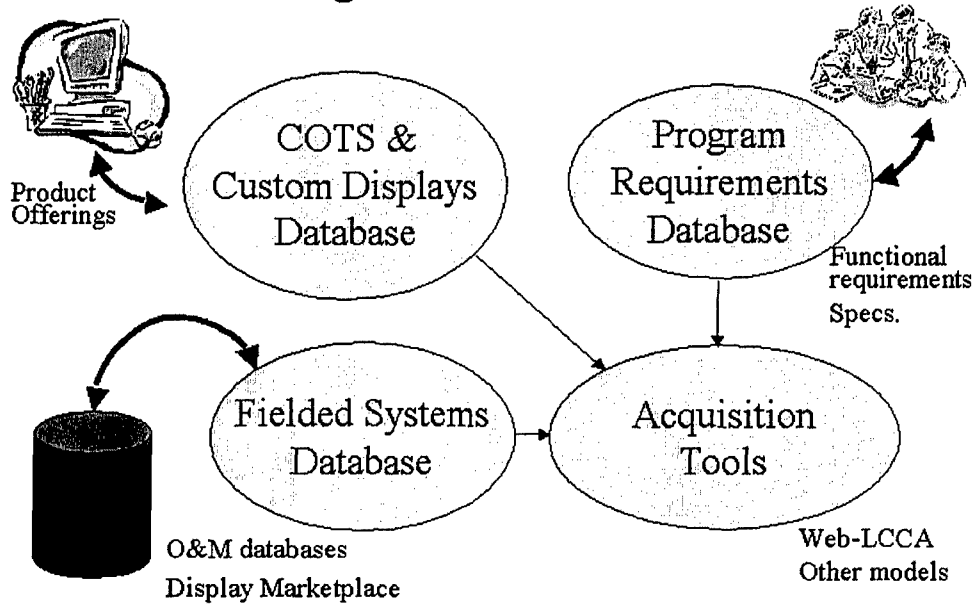


Figure 05-(03,06). Productivity Growth Enabled by Ubiquitous High-Resolution Visualization Centers (Intel).

DISPLA Segments



Tiered Search Engine

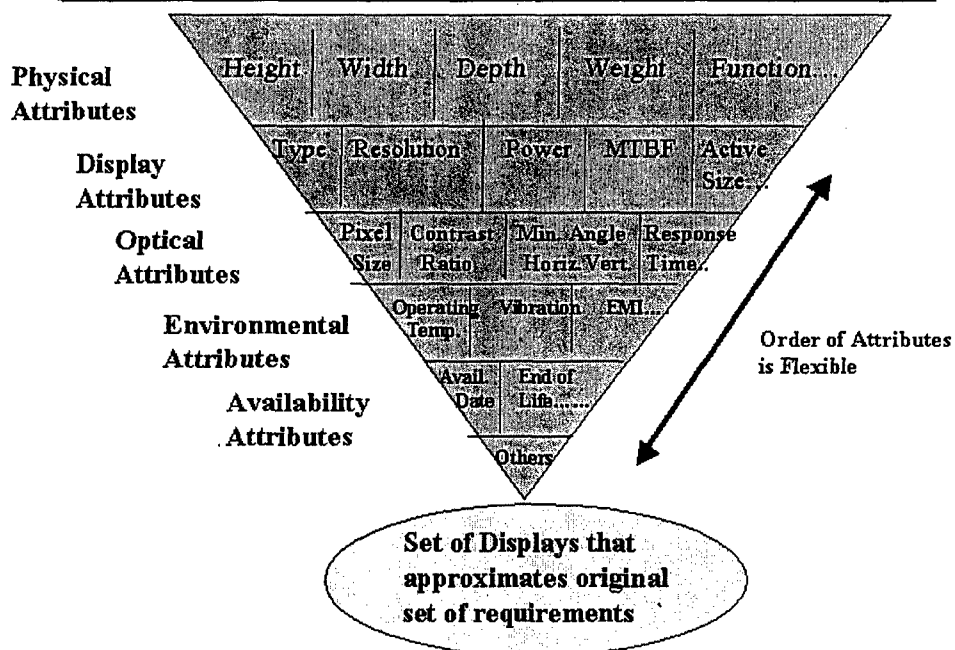


Figure 06-(18,19). DISPLA System for Support of DoD Display Acquisitions (Northrup Grumman).

SUMMARY OF COMBAT SYSTEM PRIME CONTRACTORS' PRESENTATIONS

07. *Mr. Art Behrens (Boeing):
"Boeing Displays Process Action Team (DPAT): An initiative on Flat Panel Displays"*

Mr. Behrens described an initiative taken by The Boeing Company in response to failure of the domestic sources of active matrix liquid crystal display (AMLCD) panels used on virtually all of the Boeing military aircraft. This initiative, the Displays Process Action Team (DPAT), was an Enterprise-Wide activity with membership from both engineering and supplier management and procurement (SM&P) functional organizations and multiple programs across Boeing's then three major Business Units: Aircraft & Missiles (A&M), Space & Communications (S&C) and Boeing Commercial Airplanes (BCA). The specific organizations represented were: A&M Engineering Core, A&M SM&P Core, Commercial Airplane Engineering, Commercial Airplane SM&P, A&M Mesa (AH-64D), A&M Philadelphia (RAH-66, V-22), Long Beach Engineering (C-17), St. Louis TACAIR Engineering (F-15, F/A-18), Space & Communications (Space Shuttle, Wedgetail), Aerospace Support (C-130AMP), and Phantom Works - Open Systems Architecture. The intent of the Boeing initiative has been to develop and deploy an enterprise strategy aimed at avoiding future dependence on very limited sources of critical display components. The strategy chosen is based on the use of common performance requirements and interface standards to maximize opportunities for multiple re-use and minimize supply fragmentation. The process used to develop and deploy the enterprise strategy, and a summary of the common requirements, were described. Outstanding needs in the area of cockpit displays were addressed, and, specifically, the questions that are the focus of the AGED STAR. Mr. Behrens noted that a later presentation by Boeing's Carl Vorst addresses display needs in the advanced military simulation area including high-resolution rear screen projection tiled display systems for synthetic vision out-the-window (OTW) and head-mounted displays.

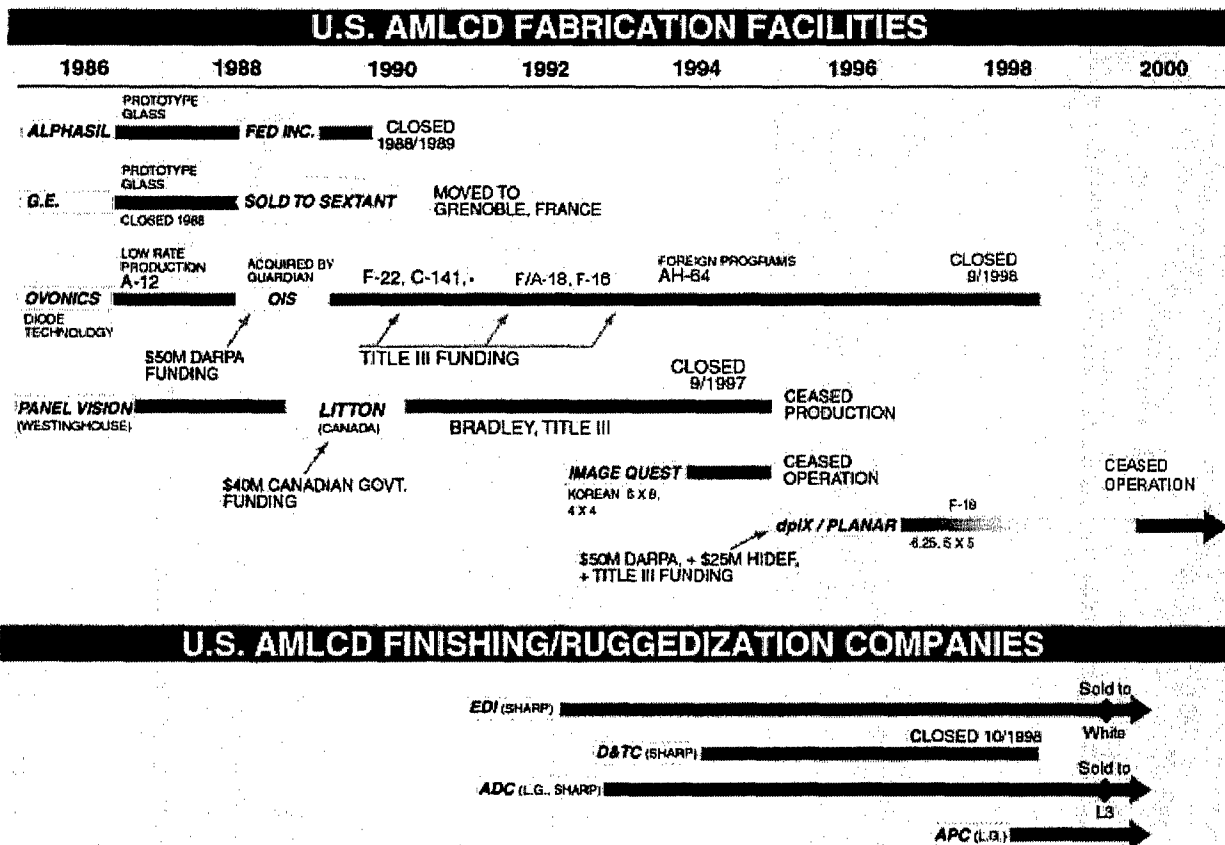
The history of AMLCD fabrication in the U.S. and Canada from 1986 to 2000 is presented in Figure 07-09. These facilities focused on combat aircraft cockpit requirements, and Alphasil and GE were among the first AMLCD facilities in the world.¹⁰ However, none of these prospective domestic sources made the large investments needed to achieve commercial viability in consumer electronics and were forced to close when custom runs for avionics displays in consumer-product driven fabs became possible for all of the leading military integrators. A new type of U.S. company began to appear that could aggregate orders across programs, negotiate deals with state-of-the-art fabs in Asia for custom runs, and ruggedize the product to the level desired by each integrator for each program.¹¹

"DoD investments in domestic AMLCD fabrication facilities during the 1990s kept the planes flying. Now, several Asian facilities meet avionics needs. The important thing is to have multiple sources."

-- Art Behrens, Boeing

¹⁰ One, ImageQuest in Fremont CA, was intended to be a temporary process development facility and was funded by Hyundai Electronics in South Korea to create its own fabrication know-how and intellectual property by working with state of the art equipment developers in Silicon Valley. Hyundai subsequently built several AMLCD mass production lines in South Korea and formed a display subsidiary known as Hydis. In late 2002 Hyundai announced a deal to sell its AMLCD display manufacturing business to China, but the deal has not materialized. The role of US AMLCD equipment makers was, and remains, critical to the Asian AMLCD mass fabrication facilities that began appearing in Japan in the 1980s, Korea in the late 1990s, Taiwan in the early 2000s, and now, China.

¹¹ Several companies have struck long-term deals with Asian manufacturers for custom runs of avionics-grade AMLCDs. American Panel Corporation aggregates requirements across programs and has a deal with LG.Philips LCD. International Display Consortium has a similar arrangement with NEC. Honeywell struck a long-term deal with Philips Components Kobe (pka Hosiden) in the late 1980s; and Rockwell, with Sharp in 1991. The Japanese manufacturers are unwilling to manufacture a military-unique product, as needed in combat aircraft.



U.S. / CANADA HAVE HAD LITTLE SUCCESS IN FABRICATING AMLCDs

Figure 07-09. History of Domestic (US, Canada) Custom AMLCD Fabrication for Avionics & Military (figure provided by Kaiser Electronics, A Rockwell Collins Company)

AMLCDs are used widely in Boeing products including the following commercial and military aircraft: 7x7 (777 and new models of 717, 737, 747, 767), MD-11, V-22, AH-64, RAH-66, F-15, F/A-18, B-1B, C-17, T-38 Upgrade, C-130 AMP, AV-8B, T-45A, and the Space Shuttle. Boeing decided to rationalize multiple requirements across these programs to eliminate arbitrary and unnecessary specification differences by developing compromises on similar requirements. The DPAT posed the question: "Why do specs differ for equivalent displays? They found some good reasons—and some not so good! These reasons were: platform/application dependence (for example, FOV for tandem vs. side-by-side cockpits); supplier capabilities (specs written to existing capability rather than minimum required performance); customer preferences; and program independence. Different programs had different schedules (technology readiness for clean sheet designs), different optimum performance objectives, and different heritage (variously, the old Boeing, North American, McDonnell Douglas). The Boeing Enterprise requirements developed by the DPAT are summarized in Figures 07-(20-24) and 07-(25-26).

Mr. Behrens strongly recommended that some display interface standards be established—something like a Mil-Std 1553B for digital video interfaces. The DoD should have all the roles identified in the terms of reference, but most funding should go to extramural efforts. One other thing DoD could do is to maintain an awareness of all programs and upgrades going on across the services and agencies and exert some control over the requirements; instead of 10 contractors for 10 programs, perhaps there could be one-two joint programs to meet the needs of the 10 programs. Two areas that merit DoD S&T

investment are immersive displays and the smarts behind the display; the price always seems to be in \$/lb, so the integration of more electronic functionality (processors, communications, etc.) is a good way to go. Regarding acquisition strategy, Mr. Behrens stated that straight COTS would not work. Boeing is striving towards ruggedized COTS, but finds that many programs are forced to use custom designs produced in a consumer mass market manufacturing facility. Mr. Behrens said DoD should find a way to give each program manager and platform office a global view, versus their current focus on their own program only. Boeing sees nothing wrong with overseas manufacturing of displays—they just want to make sure there is more than one source—but as long as a Taiwanese manufacturer can make the same display for Boeing as a Japanese manufacturer, the reliance on overseas manufacturers is a non-issue. DoD investments in displays during the 1990s have had significant payoffs—these investments kept the planes flying and minimized delivery disruptions by providing domestic custom avionics AMLCD facilities like Planar until consumer fabrication facilities appeared in Korea and Taiwan that were willing to enter long term business arrangements with aggregators like APC to meet the military-unique requirements the Japanese would not. It is important to Boeing that there be multiple sources for the same avionics-grade AMLCD.

REQUIREMENTS

CORE	TAILORABLE
Resolution	Viewing Cones
Size	Update Rate
Flicker	Latency
Pixel Response Time	Display Surface Quality
Long Term Image Retention	Element Failures
Luminance	Lumen Maintenance
Luminance Uniformity	Optical Rqmts During Warm-Up
Contrast	Crash Safety Shock
Specular Reflectivity	Equipment Generated Noise
Chromaticity	Electro-Magnetic Compatibility
Gray Scale	Sand and Dust
NVIS (Military Only)	Rain
Temperature	Explosive Atmosphere
Start-Up Time	Surface Touch Temperatures
Vibration and Shock	Glass Damage Tolerance
Temperature/Altitude	Equipment Service Life
Humidity	MTBF
Caustic Atmosphere	Built-In Test Features

Luminance Range
Commercial Transport Min $\leq 0.05fL$ Max $\geq 100fL$
Tactical Aircraft Min $\leq 0.02fL$ Max $\geq 250fL$

Display Format	Minimum Contrast Value			
	High Ambient		Low Ambient	
	Primary FOV	Extended FOV	Primary FOV	Extended FOV
Tactical Video	9:1	N/A	70:1	N/A
Graphics	5:1	2:1	50:1	20:1

SIZES AND RESOLUTIONS

Currently Supported List

D-Size (6.7" x 6.7" minimum)

6.25" x 6.25"

5 ATI (4" x 4" useable)

5" x 5"

3 ATI (2.4" x 2.4" minimum)

Future Development List

9" x 12" Class, SXGA

8" x 10" Class, SXGA or XGA

6" x 8" Class, XGA

3.75" x 5" Class, VGA

GRAYSCALE: ≥ 64 per primary color

GAMMA: ≥ 32 curves, user selectable

Figure 07-20-24. Boeing Requirements for Avionics Cockpit AMLCDs

THERMAL. Class A – Tactical Combat Aircraft. Class B – Commercial Transport Aircraft

Condition		Equipment Type	Temperature	Solar Condition
Non-Operating Extremes	Minimum	All Classes	-55C (-67F)	No Solar Load
	Maximum	Class A	85C (185F)	196 BTU/ft ² ·hr (1)
		Class B	85C (185F)	
Operating Extremes	Minimum	All Classes	-40C (-40F)	No Solar Load
	Maximum	Class A	85C (185F)	196 BTU/ft ² ·hr (1)
		Class B	70C (158F)	No Solar Load
Continuous Operation	Minimum	All Classes	-40C (-40F)	No Solar Load
	Maximum	Class A	52C (125F)	240 BTU/ft ² ·hr (1)
		Class B	70C (158F)	No Solar Load
			34C (93F)	No Solar, No Cooling

Night Vision Imaging System (NVIS) Compatibility. Tactical Aircraft Requirement Only

Applicable Documents

MIL-L-85762A "Military Specification: Lighting, Aircraft, Interior, Night Vision Imaging System (NVIS) Compatible"

JSSG-2010-5 "Crew Systems Lighting Handbook"

MIL-STD-3009 "Military Standard: Lighting, Aircraft, Night Vision Imaging System (NVIS) Compatible"

Background "Off-Pixel" Radiance Level

Excessive IR Leakage Through LC Material Impacting NVIS AGC,

Reduce via Filtering and/or Dual Backlight Implementation, Maximum "Off-Pixel" NR Level No Greater Than 5.9x10⁻¹¹

Measured at a Non-scaled White Level of 0.5fL

Figure 07-25-26. Boeing Thermal and NVIS Requirements for Avionics Cockpit AMLCDs.

08. **Mr. Kevin Greeley (Lockheed Martin):** *Presentation was not given.*

09. **Mr. Roy C. Brandenburg (Lockheed Martin):** *"AN/UYQ-70 Workstations"*

Mr. Brandenburg described the Navy's AN/UYQ-70 (Q-70) hardware and software Open System Architecture (OSA) solutions that provide the cornerstone for modernizing combat/mission critical systems for sea, land, and airborne military applications. The Q-70 is playing a key role in the modernization of combat systems on major US Navy programs. Systems with Q-70s include AEGIS (forward fit and backfit), Cooperative Engagement Capability (CEC), Ship Self-Defense System (SSDS), Advanced Combat Direction System (ACDS), Integrated Combat Direction System (ICDS), E-2C Hawkeye Surveillance Aircraft, AN/SQQ-89, TRIDENT, and New Attack Submarine (NSSN).

The Q-70 family of equipment was described as comprising display console workstations and equipment rack file server enclosures. This equipment can be mounted in surface, subsurface, airborne, and mobile environments. The Q-70 equipment is based on an open system architecture, which uses the latest available commercial off-the-shelf (COTS) components to meet United States (US) Navy-unique mission critical requirements. These requirements include real-time sensor display, voice communications, weapons control, legacy interfaces, power and cooling, survivable designs and durable

packaging. COTS components installed in Q-70 include, but are not limited to, commercial processors, operating systems, various serial and parallel I/O interfaces, various commercial storage devices, graphics processors, display panels, network devices, and touch panels. The AN/UYQ-70 family of display systems is shown in Figure 09-03.

The Q-70 program variants provide US and International military surface, subsurface, airborne, and mobile customers with a choice of modular air or water-cooled enclosures. The variants are supported with the Q-70 standard suite of operating, development, and maintenance software and support products. The variants provide the cost advantages of commercial technology, the flexibility of customized configurations, and the economy of scale of standardization to the modern combat system developer.

The prime contractor for the Q-70 program is Lockheed Martin Tactical Systems (LMTS) Eagan, MN. DRS is a key subcontractor. The Q-70 displays are COTS display technologies that have been ruggedized to meet the harsh Navy environmental requirements. It is the display provider that performs the value-added Engineering to meet the unique requirements for the AMLCD and touchpanel displays. There are three (3) prominent displays on the Q-70 program; 20.1 in. AMLCD flat panels, DMD projection displays and 6x9 in. touch panels. Each display device serves a separate function for the program.

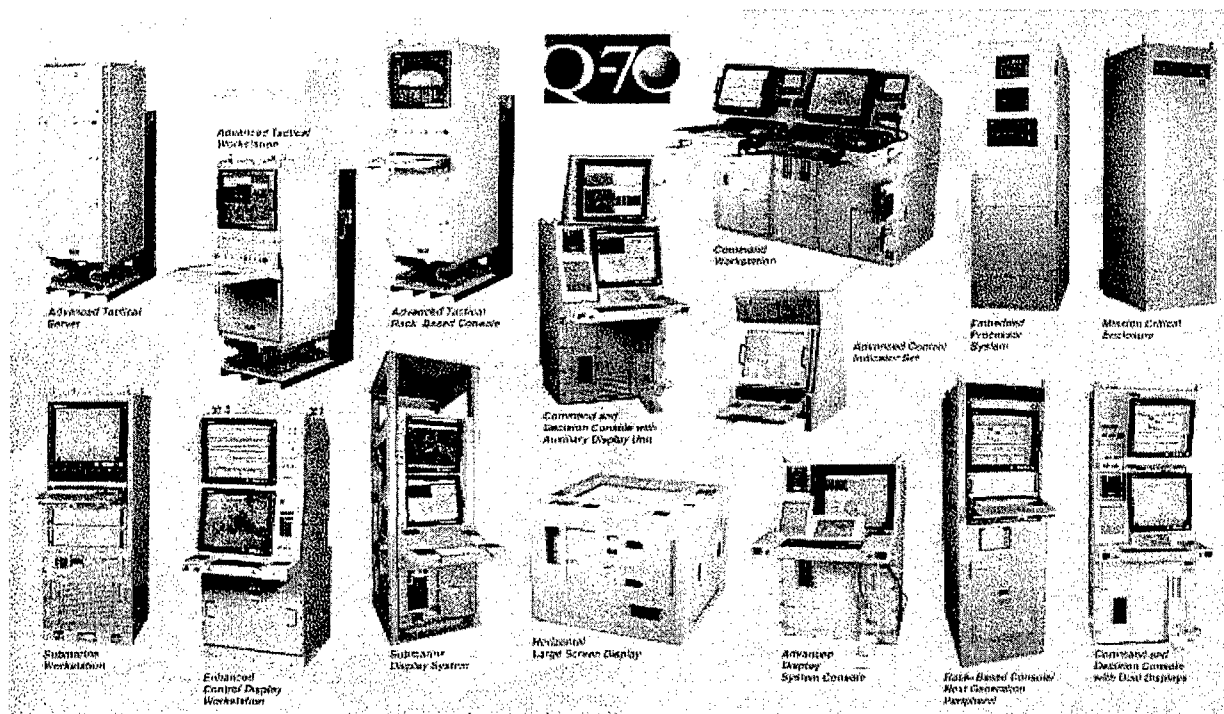


Figure 09-03. The AN/UYQ Family (Lockheed Martin Tactical Systems, DRS Laurel Industries).

The 20 in. AMLCD is the common workstation display surface. "Glass" (i.e. AMLCDs) from NEC is provided by BARCO; features include SXGA resolution, flicker compensation, an option for

100:1 dimming, touch screen option, ruggedized for Navy Applications. The DMD is the common large screen device; it is supplied by Texas Instruments (TI), a projection device oriented horizontally for electronic charting and vertically for large screen. X-Terminals on consoles are 6 x 9 in. AMLCD glass with a touchscreen; they are supplied by Daisey Data, ruggedized for Navy Applications including onboard network and Xserver.

Future display needs for the UYQ-70 family include at a minimum the maintenance of existing functional requirements for color, clarity and flicker compensation. The sailor views the display for hours on watch; it can not cause distractions or fatigue. Improvements wanted include larger display surfaces for the main displays and large screen displays, increased screen resolution and movement to HDTV, processing of live high speed video without smearing, an increased number of display surfaces on workstations both in quality and size, potential movement to thin and ultra-thin clients, the leveraging of advancements in environmental protection (shock, vibe, temperature, EMI) to hold down display costs, introduction of holographs and 3D, and ensure that units are affordable and supportable (cradle to grave).

**10. John Geddes (Exponent Inc.); SFC Chris Augustine (TRADOC):
"Land Warrior Display Solution"**

Mr. Geddes noted that Exponent Inc. is the Army's prime contractor for the Land Warrior program and that the displays are integrated by a subcontractor, Kaiser Electro-Optics (KEO) in Carlsbad CA. KEO, in turn, uses a miniature active matrix organic light emitting diode (uAMOLED) display manufactured by eMagin Inc. in East Fishkill NY. Mr. Geddes introduced Sergeant First Class (SFC) Chris Augustine, who is a TRADOC System Manager-Soldier staff member for the Land Warrior TRADOC System. SFC Augustine brought the Land Warrior ensemble and demonstrated it both during the presentation and the following break. Mr. Geddes and SFC Augustine noted that Land Warrior is the U.S. Army's premier program for enhancing the infantry soldier's battlefield capabilities through the development and integration of an assortment of Army systems, components and technologies into a cohesive, timely and combat effective system. It is a first generation modular, integrated fighting system for dismounted combat soldiers. The Land Warrior program is designed to maximize existing, mature technologies to correct soldier deficiencies in the near term and bring the soldier into the digitized battlefield of the Objective Force.

One of the principal motivations for building an integrated soldier combat system was the recognition that the weight of the equipment carried by infantrymen in modern combat is "out of control". One of the system-level requirements for Land Warrior is that, at a threshold level, it could not increase the weight carried by the soldier. The current U.S. Army infantryman carries approximately 93 pounds of clothing and individual equipment, including his individual weapon and ammunition. Most infantrymen carry additional organizational equipment that further adds to the cumulative weight each man carries. Analysis by the Army in the early '90s led to the conclusion that integration of individual items would lead to a weight reduction in the individual devices by reducing redundant capabilities. This led to an additional concept for integrating power sources into a single power supply, eliminating the logistical burden of maintaining a large family of batteries and accruing advantages of commonality.

The mantra of the Land Warrior program became "Weight-Space-Power-Balance". In selecting the technical approach for providing a display, the performance requirements stated for both the overall system and the display were considered in great detail. A key consideration was the power consumption characteristics of each display alternative, in the context of the Operational Mode/Mission Summary parameters of system usage. The power consumption characteristics were evaluated in the larger context of system power consumption and tradeoffs with other system components. Since the display is mounted on the helmet of the soldier, weight and balance considerations were also crucial. In addition to system weight requirements and goals, the Army has established head-borne weight limits that had to be

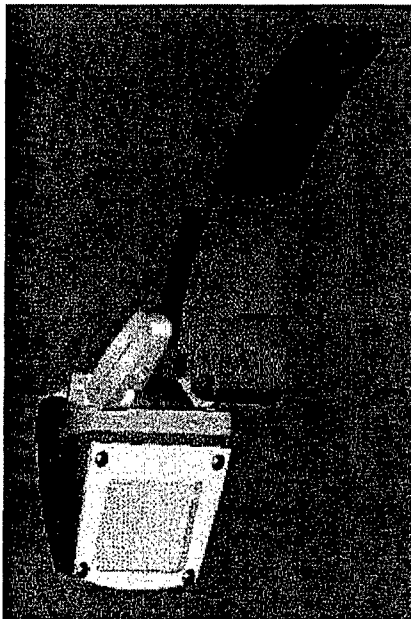
considered. The impact of existing devices worn by infantrymen, like image intensifiers, plus the weight of the existing helmet in common configurations were duly considered.

Not least, the performance characteristics of the alternative display solutions were considered. The performance requirements for the display were broadly written to provide maximum latitude for selecting the best technical solution. The required capabilities are (1) a removable color user display, readable during day and night operations while wearing chemical protective equipment, (2) when Level III laser eye protection is worn, the display shall be usable by the soldier, and (3) the display shall provide sufficient resolution for the soldier to read messages, images, maps and graphics. The Land Warrior HMD requirements are depicted in Figure 10-01-12-14. The HMD and its bracket are less than 10% of the 5.5 lb. total weight limit for the LW helmet system.

Future display features wanted for traditional displays are higher resolution and flexible physical design. Features wanted for non-traditional displays are see-through and retinal imaging.¹²

Land Warrior HMD

- Color, high-resolution solution: 800 x 600 miniature AMOLED
- Lower power than miniature AMLCD
- Fewest no. of conductors = smallest cabling



System Impact on HMD

- Minimize weight of display module and electronics
- Minimize thermal signature
- Withstand exposure to solar radiation
- Power off when not in use, but resume very quickly to display alert messages
- Minimize cable size
- 1394 digital video interface for weapon-sighting imagery

Figure 10-01-12-14. Land Warrior Helmet Mounted Display (HMD).

¹² In February 2003 the U.S. Army Rangers rejected the Land Warrior helmet system. There were no negative comments regarding the display device, just the system integration. PEO Soldier is addressing integration concerns.

SUMMARY OF DISPLAY COMPONENT MANUFACTURERS' PRESENTATIONS

11. **Mr. James Niemczyk (American Panel Corporation):**
"APC and LG.Philips -- A Proven Business Model"

Mr. Niemczyk of American Panel Corporation (APC) in Alpharetta GA described their partnership with LG.Philips LCD in South Korea by which APC aggregated demand for avionics-grade displays among military avionics integrators and obtains a custom-design run in a LG.Philips LCD high-volume TFT AMLCD fabrication facilities (capital cost: \$800M to \$1.2B per fab.) in Gumi, South Korea. The business model is summarized as "custom designed flat panel modules for military displays from a consumer oriented fabrication facility." LG.Philips LCD provides high performance flat panel cell technology, extensive R&D capabilities, and very high quality mass production capabilities. APC provides aggregate orders (minimum: 1000 per run), requirements consolidation across integrators and programs, high performance ruggedizing technology as needed, and avionics and applications experience in avionics, military, and industrial environments. The division of labor between APC and LG.Philips LCD is summarized in Figure 11-17-22-23.

LG.Philips LCD is a joint venture between LG Electronics and Royal Philips Electronics, with headquarters in Seoul, South Korea. LG.Philips LCD is the world's #1 producer of LCD monitors, Notebook PCs and LCD TV modules. LG.Philips bought the world's first generation five (Gen 5) TFT LCD fabrication facility (1000 x 1200 mm substrate size) on line in the first quarter of 2002 at a cost of about \$1B. LG.Philips is now the world's No. 1 volume manufacturer of TFT LCDs. Several fab generations and economy of scale in reducing unit cost are illustrated in Figure 11-07. LG and LG.Philips facilities developed during the past 10 years are depicted in Figure 11-08.

APC was founded as a result of the realization that a facility that manufactured only customized AMLCD cells is not economically feasible because of three reasons: (a) the investment in capital equipment is extreme; (b) the yield and quality requirements are not achievable on low volume lines; and (c) the time to market is too slow on a low-volume, custom-only fabrication facility (technology advances too quickly at all levels—materials, cell and display design, manufacturing technology). Display needs are typically in months, not years.

Volume demands for avionics displays are too small to make a custom fab economically viable. LG.Philips-LCD manufactures >18M panels per year. All avionic FPD requirements (20,000 panels) represent 0.1% of only LG annual production. All 20,000 avionics panels could be manufactured in less than 10 hrs if all the same part number (they are, in fact, dozens of part numbers).

On the other hand, avionics displays require higher performance than those in consumer products. While the high-capital cost TFT line can be used on a "fab time purchase basis" the design itself needs special attentions. All avionics display requirements are not the same (and never will be), and there is a core performance level that must be achieved, and that can only be achieved through customization. Customization can only be accomplished using leverage from a consumer facility for the TFT step. Performance requirements drive the need for a customized product. Customization of the cell at the point of manufacture is necessary for the following steps: (a) high temperature fluid; (b) patterned column spacers; (c) ultra low reflection black mask; (d) adhesives; (e) form factor requirements; (f) electrical and video interface.

Mr. Niemczyk stated that obsolescence is the number one issue that APC sees with prime display manufacturers (integrators of flight instruments like Honeywell, BAE, Rockwell, etc.). The APC products are guaranteed to have form / fit / function display modules available for 10 years. This guarantee is unprecedented in the electronics industry. No other AMLCD supplier can make this claim.¹³

Display cell sizes now offered by APC as a result of its relationship with LG.Philips LCD include three categories: (a) standard avionics sizes ranging from 3ATI (image area: 2.41 x 2.41) to 6.21 x 8.28 in. image area; (b) semi-custom avionics sizes ranging from 4 to 22 in. diagonal (image area 3.17 x 2.38 to 18.52 x 11.35 in.); and (c) four custom avionics products with case size (image size) of 3ATI (2.26 x 2.26 in.), 5x6ATI (5.14x 3.86 in.), 7.25x7.25 in. (6.25x 6.25 in.), and 9.00x 5.5 in. (8.00x4.50 in.).

Ruggedized and commonality product features for avionics and military applications should include electronic horizontal/vertical mirroring or flip to allow use in multiple configurations/orientations, very wide temperature range operation (-20 to +55 °C) with no adjustments, temperature compensation, or heaters required, extremely wide temperature range operation (-54 to +85 °C) with dynamic temperature compensation and heaters, cropped corners to facilitate tight packaging (conforms to ARINC standards), portrait or landscape or non-standard aspect ratios, no image retention at any gray scale level, and high temperature clearing point LC fluid. Other desirable features include the use of patterned spacers to eliminate sensitivity to touch—this is a most dramatic improvement in ruggedized AMLCD technology with direct applications for ruggedized touch screens as it prevents spacer migration under vibration and virtually eliminates image distortions under shock and vibration. Another desirable feature is an Electro Graphic Input Panel (EGIP) touch screen integrated in the front polarizer to eliminate additional “add on” touchscreen. APC offers all of these value added features in a menu of options available to the line replaceable flight instrument integrator.

Mr. Niemczyk noted that display requirements are driven by active area, performance, and obsolescence. Three years ago (1998-1999) the AMLCD was the highest risk item in the display. Now (as of 2001-2002) all three requirements have been successfully achieved. Mr. Niemczyk recommended that DoD take advantage of advancements in AMLCD technology from the consumer market and apply them to the custom market in terms of resolution, display size, robustness, and integrated technology.

Mr. Niemczyk further recommended that DoD fund AMLCD enhancement R&D to bring improved technology to the market faster. These enhancements can be incorporated into the current products while maintaining forward and backward fit and to minimize or eliminate obsolescence.

¹³ APC has the only such long-term relationship that will service military-unique applications for DoD like combat aircraft cockpits. For dual use applications where a civil aviation or other application exists first, then a military derivative of the same AMLCD is developed, such long term relationships exist between Honeywell and Philips Components Kobe (pka Hosiden), Rockwell and Sharp, and, recently, the International Display Consortium and NEC. Thales has a similar relationship to Thompson LCD in France for military and civil avionics AMLCDs.

American Panel Corporation (APC) Products in Partnership with LG.Philips LCD

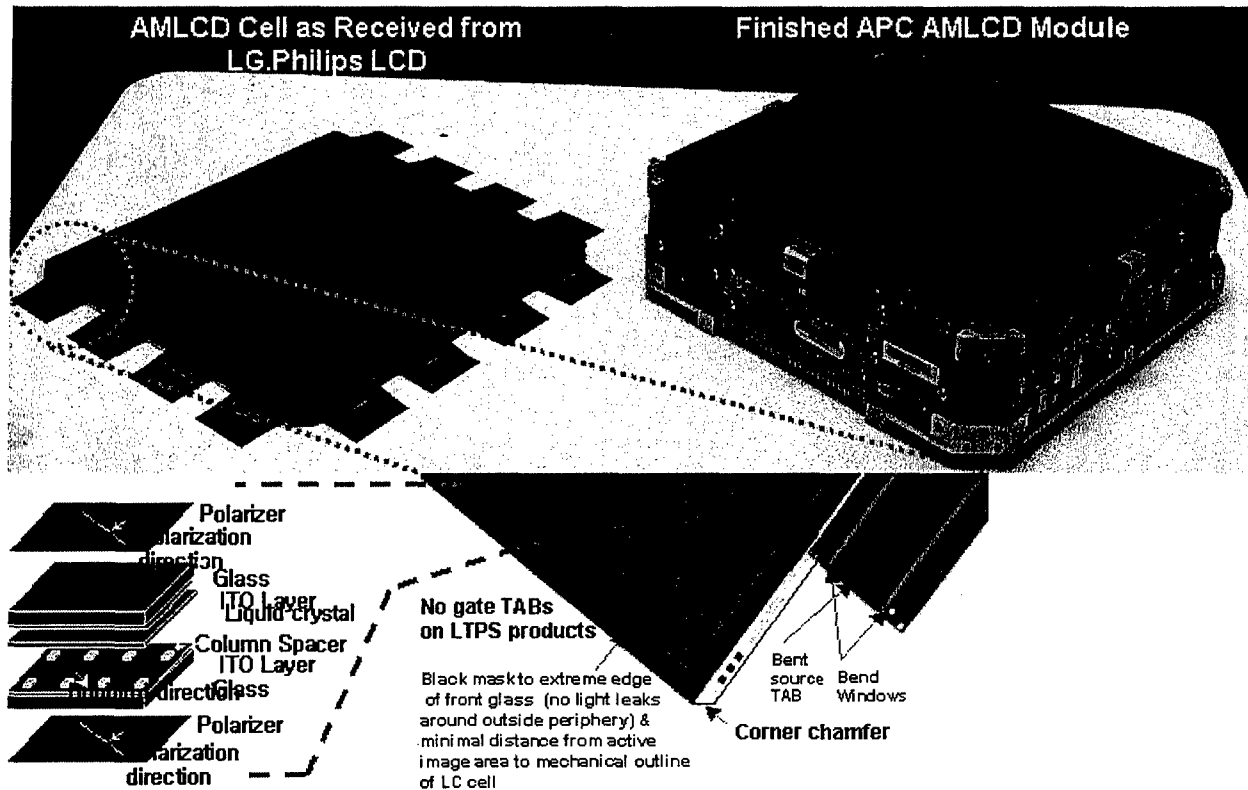


Figure 11-17-22-23. Division of Labor in APC Partnership with LG.Philips LCD.

Bigger input sheets (mother glass) means more displays per sheet as well as larger and more economical displays; for 15-inch, for example, "15 up" on P4 is far less cost per display than "2 up" on P2

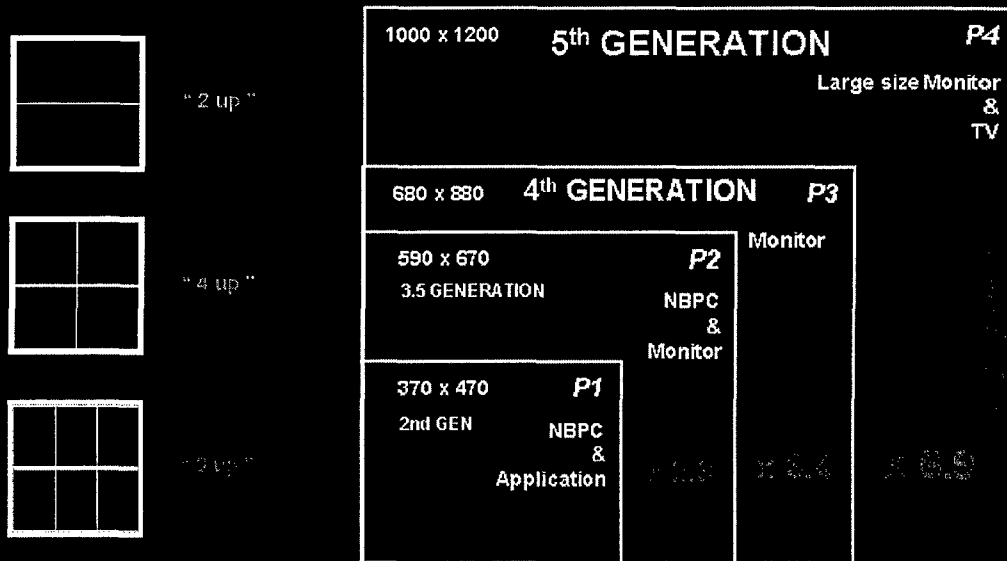


Figure 11-07. Market and Outlook for Substrate Size: Fabrication Facility Generations.

Portfolio of LG.Philips factories allows many economies of scale.






	R & D	Fab 1	Fab 2	Fab 3	Fab 4
					
Glass Size (mm ²)	300 x 350 100 x 100	370 x 470	590 x 670	680 x 880	1000 x 1200
Generation	R & D	2nd	3.5th	World's first 4th Gen. Fab	World's first 5th Gen. Fab
Input Capa (Glass/Month)	0.5K	90K	80K	60K	30-60K
Mass Production Started		3Q 1995	4Q 1997	2Q 2000	1Q 2002
Panels Produced	New Technology Development	NBPC & Application	NBPC & Monitor	NBPC & Monitor	NBPC & Large Monitor & LCD TV

Figure 11-08. Portfolio of LG.Philips Factories.

12. **Mr. Ollie Woodard (Kopin Corporation): "Success Story of COTS Display Development"**

Mr. Woodard presented the Kopin development of miniature active matrix liquid crystal display (uAMLCD) devices as a success story for COTS creation. The uAMLCD technology was created under Air Force, DARPA, and Army research funding totaling some \$65M from 1984-2002, and has been commercialized by Kopin in partnership with United Microelectronics Corporation in Hsinchu, Taiwan.




The initial technology came from the Air Force MIT Lincoln Labs (LL). Kopin was founded out of LL in 1984 and issued its initial public offering (IPO) in 1991 on the strength of receiving funding from AFRL in 1990 to demonstrate its circuit transfer technology that enabled high temperature single crystalline silicon processing in integrated circuit (IC) microelectronics fabrication facilities followed by circuit lift-off and transfer to a transparent glass substrate suitable for a light valve display. Subsequent DARPA S&T programs managed by the Army and Army-funded R&D programs enabled Kopin to win a competition for the helmet display program for the RAH-66 Comanche by the HMD contractor, Kaiser Electronics. Subsequently, the team involving Kaiser Electronics won the Air Force/Navy/Marines/UK competition for the F-35 JSF program and selected an HMD design based on the Kopin uAMLCD. Kopin now has over 100 patents on uAMLCD technology. The business focus is uAMLCD development and manufacturing via wafer engineered materials with strong, Asian, industry partners. Kopin claims to be the world's leading provider of microdisplays, shipping about 500,000 per month.. Beyond the HMD systems for the RAH-66 and F-35 aircraft, HMDs based on Kopin uAMLCDs have been evaluated for dismounted combatant applications by USAF SOCOM 24th TAC, the Fort Knox CVC, the Army Digital Military Police School, for maintenance by CASCOR, and for surgery by the Fort Detrick Army Madigan Medical.

Current Kopin CyberDisplay™ uAMLCD commercial products and ruggedized applications are shown in Figure 12-06, 13, 14). Relative to currently fielded HMD systems for pilots, which are all based on miniature CRTs, HMD systems designed with the Kopin products have several dramatic advantages: smaller form factor, higher resolution, color, equivalent price, less weight, less power consumption, and more ruggedness. Sales of Kopin products rose from \$2.9M in 1998 to \$22.2M in 2001. Kopin consumer products range from viewfinders in camcorders (JVC, Panasonic, Samsung) and cameras (Mustek Smart 350, SoundVision SV1301 DSC) to head-mounted displays (IBM BodyWorn ThinkPad, Oriscap Personal DVD Viewer) to hand-held devices (Navitrac Hand-Held GPS, IIS iCom Personal Web Browser). Kopin ruggedized display applications and engineering evaluation efforts include the DIOP Thermal Clip-On Sight, the Raytheon-Nytech-BAE Systems Light Thermal Weapon Sight (LTWS), the Kaiser Electronics Comanche HIDSS, the FLIR Systems HHTI, the Alliant Technology OICW, the FLIR Systems-BIRC TOW Missile System, the DIOP HHIR Camera, and the BAE Systems NVG HUD (E-HUD/O-HUD).

Mr. Woodard stated that transitioning technology out of the laboratory and into products is the key to future performance improvements. He cited six factors that are key to technology deployment: (1) government/industry partnership in technology spurs development; (2) technology transfer to commercial applications is crucial to availability; (3) a high volume business base—needed for stable source of supply; (4) a COTS manufacturing process that supports low volume military needs; (5) EMD programs to transition to production and deployment; (6) suppliers committed to supporting DoD applications.

Mr. Woodard summarized by stating that the DoD/Government investment in technology has paid off. Government/Industry partnerships are invaluable when executed successfully. The Kopin uAMLCDs have successfully transitioned to high volume commercial markets, and a production process leveraging the commercial manufacturing facilities has been proven for low volume, high performance DoD displays. Mr. Woodard also presented a technology roadmap that supports continued improvements and evolution of uAMLCD technology (available to AGED and government personnel only).

Kopin CyberDisplay™ Products

	0.25" D	Pixels: 320 X 240 Color: Yes Monochrome: Yes Ruggedized: No Availability: Pre Production Volume: 400 to 500K/ Month
	0.38" D	Pixels: 640 X 480 Color: Yes Monochrome: Yes Ruggedized: Yes Availability: Pre Production Now Capacity: LIRIP (25K, 640) Q2
	0.61" D	Pixels: 1280 X 1024 Color: In Development Monochrome: Yes Ruggedized: Yes Availability: Pre Production Now Capacity: LIRIP (50K, 640) Q2

Kopin Ruggedized COTS Products

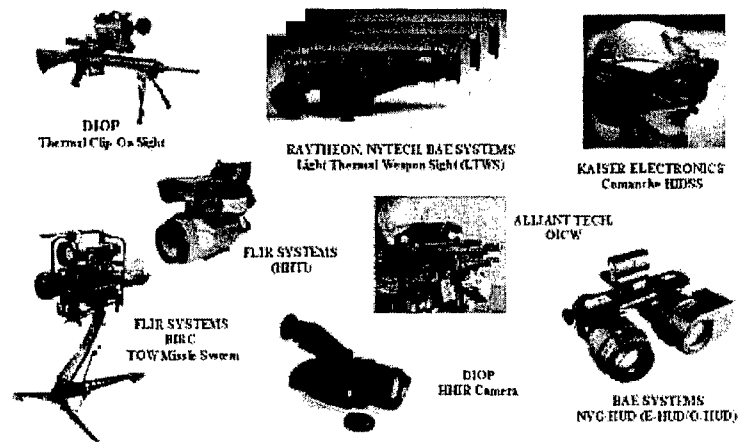
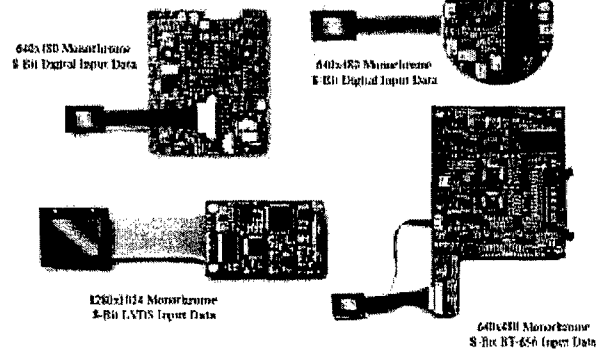
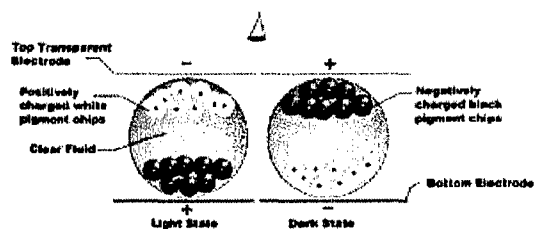


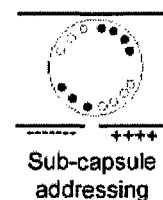
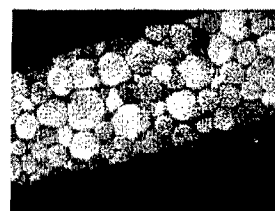
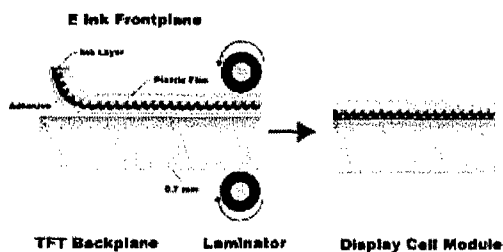
Figure 12-(06,13,14). Kopin Micro-AMLCD Commercial Products and Ruggedized Applications.

13. **Dr. Peter Kazlas (E Ink Corporation, Cambridge, MA): "Paper-like Electronic Ink Displays"**

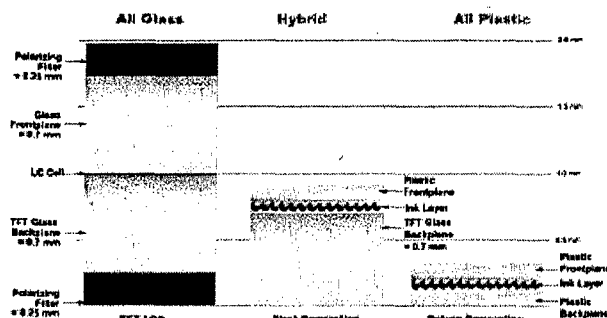
Dr. Peter Kazlas of E Ink Corporation of Cambridge MA provided an overview of electronic ink displays, described key technology development areas, and discusses potential military applications. The presentation also addressed DoD's role in the advancement of display S&T. The electro-phoretic ink display (EPID) operates as illustrated in Figure 13-04-08,15. These displays do not operate at video rate, but once written, images are retained without expenditure of power. Some EPID prototypes build to date are illustrated in Figure 13-25-26-28-29. E Ink has a goal of creating products like Radio Paper™, a tabloid size newspaper layout with flexible pages and wireless data daily. Broadband and wireless drive pervasive computing...anywhere, anytime. Displays are the primary interface for computing information. The future belongs to display solutions with readability and portability. Flexible displays can offer rugged screens, ultra thin modules enabling sleek sturdy devices at competitive prices in both existing markets like handhelds and laptops, and in new markets like smart cards, wearable displays, and large-area signage. Dr. Kazlas noted that mobile flat panel displays are one of the fastest growing display markets with market size estimates exceeding US \$14B by 2005 (ref: DisplaySearch). As of 2002, pervasive computing enabled by the latest advances in wireless bandwidth and processor technologies places new demands on mobile displays requiring higher information content, ease of readability in dynamic environments and lower power consumption - while not compromising device portability.



Contrasting pigments -> High reflectance and contrast
Microcapsules -> Printable, simple assembly, reliability



Resolution is governed by the movement of individual sub-micron pigment particles, not by microcapsules.



Comparison of Power Consumption For LCD and Electronic Ink Display Technologies

Display Technology	Power Consumption (5" QVGA format)	Power Consumption (8" SVGA format)
Transmissive color AMLCD (common PDA)	1000 mW	3830 mW
Reflective monochrome STN LCD (common PDA)	60 mW	n/a
Reflective color AMLCD (common PDA)	25 mW (LTFS)	600 mW
Monochrome electronic ink (one update per 10 seconds)	0.7 mW	7.1 mW
Monochrome electronic ink (one update per 60 seconds)	0.1 mW	1.2 mW

Note: Figures for LCD displays based from commercial product literature. Figures for monochrome ink displays calculated based on projected commercial device performance. QVGA is defined as a 320 x 240 pixels while SVGA is defined as an 800 x 600 pixels.

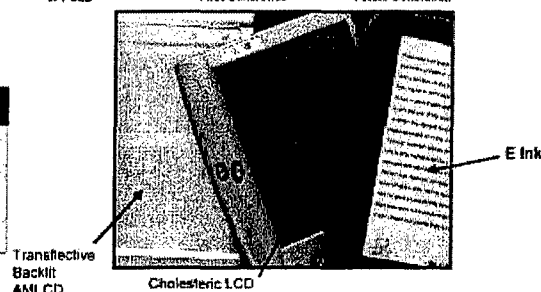
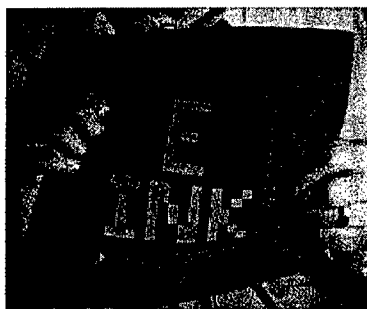


Figure 13-04-08,15. Electrophoretic Ink Display Technology.

The most advanced portable information appliances now use glass-based transreflective mode twisted nematic (TN) and super-twisted nematic (STN) liquid crystal displays (LCDs) for high- and low-end applications, respectively. These displays are continuously addressed and require a backlight to achieve the necessary brightness for ambient light viewing. The inherent reflectance and transmittance of these displays exhibit large angle dependence and require additional light management films that increase cost. Even with these solutions, readability is compromised in certain usage environments. These glass-based displays also need to be ruggedized for mobile applications, adding package weight and cost to the final device. As mobile displays get larger to accommodate the demand for more computing higher device cost and weight, and lower device portability. Mobile devices can be much better served by display solutions that offer both high readability and portability.

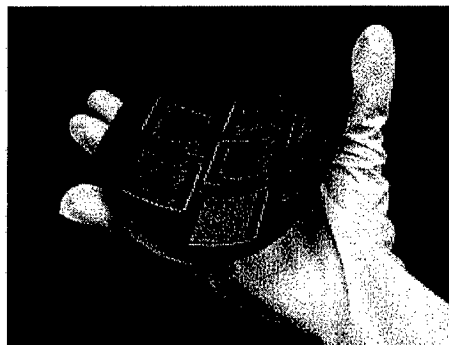
E Ink's electronic ink displays offer a unique set of performance ultra-low power consumption and thin, light form factor. Additionally, electronic ink can be easily printed on large sheets or reels of plastic and laminated to a backplane, simplifying display assembly and, thereby, reducing cost. Combining a plastic frontplane of electronic ink with a high-resolution active-matrix backplane produces a display that delivers high information content and excellent image quality in a thin form factor.

World's First Flexible Ink Display, Nov 2000



World's first electronic ink display built with organic transistors with Bell Labs.

Flexible TFT Backplane, Nov 2001



Conformable & flexible displays, Dec 2001



- Driven by +/- 12 V
- Ink on paper appearance
- Maximum white state reflectance 37%
- Contrast ratio 12:1
- Full viewing and illumination angles
- 2.5 cm minimum bending radius
- 100x80 pixels
- 1.6" diagonal
- 0.3 mm thick
- +/- 15 V
- Reflectance > 30%
- Contrast ratio > 10:1

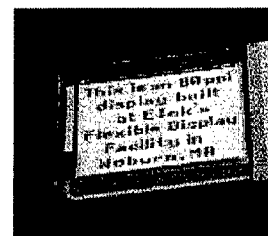


Figure 13-25-26-28-20. Electrophoretic Ink Display Prototypes (non-video).

First generation high-resolution electronic ink displays are built by laminating an electronic ink plastic frontplane to a conventional glass-based amorphous-silicon (a-Si) TFT active-matrix backplane. In June 2001, E Ink and Philips Components demonstrated the first commercial prototype 5 in. qVGA active-matrix electronic ink display. The total thickness of the display is about 1 mm, nearly half the thickness of a typical LCD. Commercialization of this active-matrix EPID technology is slated for 2003.

E Ink is currently developing active-matrix electronic ink displays, which incorporate TFT backplanes on flexible substrates; enabling ultra-thin, flexible paper-like displays. In September 2001, E Ink opened a new flexible microelectronics facility in Woburn, Massachusetts. At this facility, E Ink is developing microelectronics, including flexible transistors, which will enable E Ink to create paper-like display prototypes. This facility will create flexible electronic ink displays based on new transistor designs and novel materials and processes. Scientists are developing traditional silicon-based TFTs as well as a variety of printed conductor and semiconductor materials. E Ink is currently talking with potential TFT manufacturing partners to transfer and scale-up flexible transistor processes for mass production.

Mr. Kazlas stated the need for access to a TFT development facility and, furthermore, that without a U.S. flexible TFT facility, U.S. display companies are at a severe disadvantage and blocked from competition. Currently, U.S. display companies have but limited access to TFT backplanes. This limitation slows or blocks U.S. companies from testing novel materials on TFT backplanes, demonstrating their technology in high resolution, and distributing samples to customers to develop demand. The TFT makers in Asia have enormous leverage by restricting supply—they have exhibited a limited willingness to provide custom TFT backplanes and then only at a hefty price of admission of over \$500K (for each design). The Asian TFT companies are LCD-centric, but LCDs are not well-suited to flexible displays and Asia has been slow to promote flexible backplanes. The U.S. is a world leader in new technologies competing with LCD where flexible is a key advantage, like OLEDs and reflective EPIDs. The LCD players are threatened by flexible displays and will do little to support U.S. efforts in this area.

Mr. Kazlas closed with his perspective to DoD in terms of funding, focus, facilities, and model. DoD should fund display S&T in leap-frog technologies: flexible displays, low-cost display manufacturing, and intelligent displays. If TFT fabs are too expensive, DoD should invest in programs to deliver inexpensive TFT technologies. DoD should focus energy on inter-mural programs where government labs, industry, and academia work in a true partnership (e.g. federated displays labs). DoD should fund a network of small display development labs as dual-use facilities that can also operate as small volume display suppliers. DoD should adopt a dynamics model, as the display industry is very fast-paced and ever changing.

14. **Dr. Julie J. Brown (UDC): "Organic Light Emitting Diodes--Recent Progress Towards Commercialization and Future Technology Directions"**

Dr. Brown stated that organic light emitting diode (OLED) technology is making tremendous progress towards becoming a viable display technology for a wide range of product applications. Over 100 companies and universities are engaged in OLED R&D, all driven by the promise of wide viewing angle, bright, low power consumption, full-color, video rate, thin light-weight products. While initial commercial and military opportunities are for small area mobile products, such as cell phones and PDA, there is considerable interest in larger area applications, such as monitors and TVs. Furthermore, novel OLED features of transparency and flexibility, and the potential to enter new markets like lighting and wearable electronics, have captured the imagination of many product designers. Figure 14-04 presents a roadmap for OLED products, prototypes, and concepts starting with introduction of the first successful product in 1997 (low information content monochrome green display in a Pioneer car radio) to the current 2002 products (small qVGA color display in cell phones and cameras) to flexible OLEDs by 2005. In addition to displays, lighting is another application of OLED technology, including room lighting and backlights for miniature AMLCDs. Today the UDC business plan includes licensing its OLED technologies and process technologies to mass market manufacturers like Samsung SDI in Korea and entering joint development agreements with production equipment manufacturers like Aixtron in Germany.

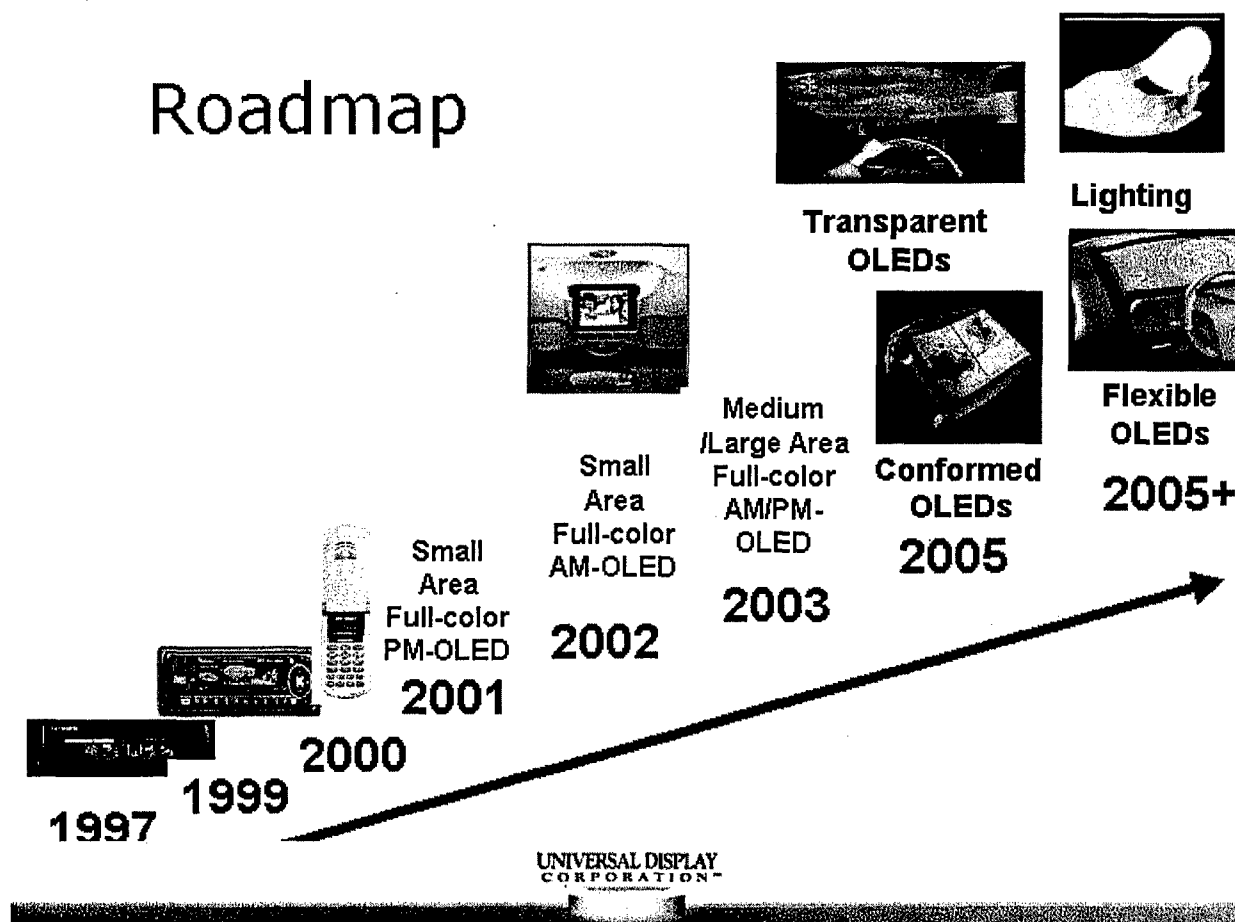


Figure 14-04. Roadmap for OLED Products.

While there have been tremendous advances in the overall performance of OLED devices over the last few years, the challenge to produce low power consumption products with requisite color purity and lifetime still remains. UDC is addressing low power consumption with its proprietary phosphorescent OLED (PHOLED™) technology. The first efficient small molecule OLED devices were reported by Tang et al. from Kodak in the 1980's. In 1990, light emission was also reported from large molecule polymer organic light emitting diode (PLED) devices. In both of these conventional fluorescent OLEDs, light emission occurs as a result of the recombination of singlet excitons. In 1998 researchers at Princeton University and the University of Southern California demonstrated phosphorescent OLEDs (PHOLEDs), where light emission occurs from the radiative recombination of triplet excitons, formed as a result of inter-system crossing of singlet to triplet states through the presence of a heavy metal atom. This pioneering work has resulted in internal quantum efficiencies approaching 100%. Based on these inventions and a strong partnership with the universities, UDC is developing the next generation of high efficiency phosphorescent OLED materials and devices. PHOLEDs provide significant performance advantages for full-color OLED displays, and may even enable the opportunity for OLEDs to be used for niche and, some day, general lighting purposes. Dr. Brown also described recent UDC progress in flexible and transparent OLED technologies. To date, OLED displays are being fabricated on rigid substrates such as glass or silicon wafers. UDC is developing a new class of OLED displays on flexible substrates, or FOLEDs, for flexible organic light emitting devices. In addition to flexibility, FOLEDs enable new display features such as conformability, lightweight, and inherent impact resistance. In order to bring this technology to the marketplace, there are a number of exciting challenges to be tackled. A photograph of a video-capable flexible OLED invented by UDC is illustrated in Figure 14-29.

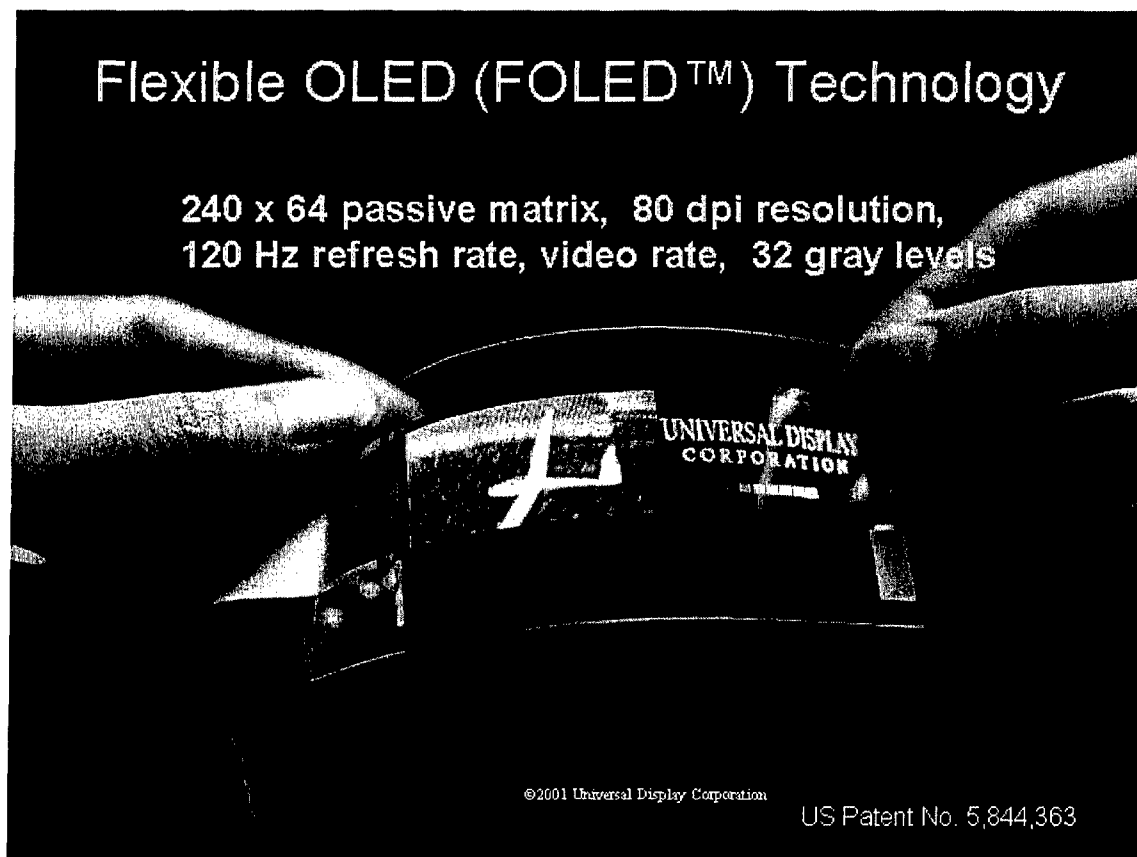


Figure 14-29. Flexible OLED Invented by UDC.

SUMMARY OF DISPLAY SUBSYSTEM INTEGRATORS' PRESENTATIONS

15. Dr. Kalluri R. Sarma (Honeywell): "Avionic Display Systems"

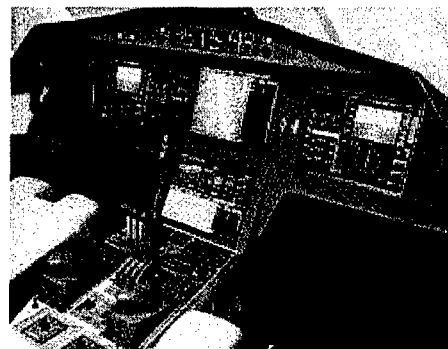
Dr. Sarma noted that Honeywell's Avionic Display Systems business includes the commercial air transport, business jets, regional aircraft and general aviation, and space and military markets. The display technologies employed and the display products (in current production as well as under development) were discussed. Honeywell's display business model for the development of full custom displays (as well as for ruggedizing the COTS displays in certain instances) for the demanding avionics market include, having strong internal display R&D efforts in the areas of display media technologies, display design, graphics generation, and systems design, and having a close long term working relationships with selected manufacturing partners / suppliers. Honeywell's current development efforts include development of next generation avionics AM LCD technologies, and evaluation and development of Projection Displays for the avionics and military markets. AM OLED technology is also being evaluated as a potential next generation display technology. Honeywell pioneered flat panel glass cockpits; some key avionics cockpit display systems developed by Honeywell are summarized in Figure 15.04 and Figure 15.10.

Honeywell Avionic Display Systems

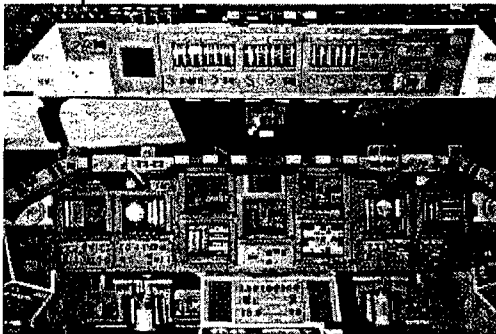
Boeing 777



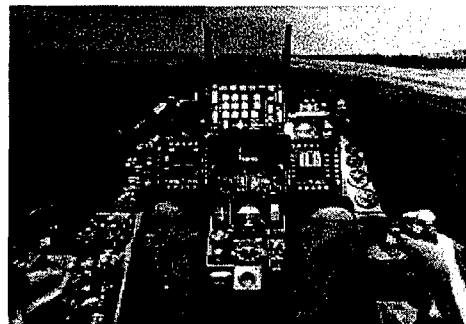
Dassault Falcon 900



Space Shuttle Atlantis



F-16



Honeywell

Aerospace Electronic Systems

4

Figure 15-04. State-of-the-Art Flat Panel AMLCD Glass Cockpits.

The desired display technology improvements include – higher efficiency (lower power consumption, weight and volume), higher level of ruggedness, higher luminance (e.g. 500 fL) with longer life, video response for all graylevels, lower ambient light reflection, higher resolution (e.g. 300 ppi and 25 M pixels), 3D, high bandwidth display interfaces, intelligence at the pixel and higher level of system integration. Just as the development of AM LCD has enabled notebook computers and a revolution in mobile computing and communications, the above advances in the display technology will enable revolutionary advances in war fighter's capabilities and effectiveness.

It is important for the DoD S&T community to undertake the items (a) through (f) in the list provided in Additional Question #2 of the Terms of Reference on page 3. The rationale for this recommendation will be presented. With respect to allocation of resources (in person years and program dollars), the following distribution is recommended: (a) 6 %, (b) 4 % (c) 5% (d) 20 % (e) 65 % (f) include systems research in item (d) to better define the display system requirements.

Near term needs (<5 yrs) are: (1) Military avionics specific AM LCD improvements, (2) Improved light sources, screens, and application specific system level solutions for projection displays, (3) Improved OLED materials with higher efficiency and longer lifetime, active matrix devices and circuits for driving OLED displays. Mid-Term needs (5-10 yr) are: AM OLED display systems for avionics, highly rugged displays fabricated using plastic substrates, projection display systems with efficient and compact solid state lasers, 3-D displays, high-resolution displays (e.g. 300 dpi, 25 M pixels, with appropriate sizes), intelligent displays. Long-Term needs (>10 yr) are: very low-cost AMOLEDs with organic TFTs, flexible intelligent displays, and integration of the system on the display panel.

DoD must motivate the industry by facilitating participation in items all phases of display R&D, and funding military specific R&D, and prototype display development efforts.

The display-manufacturing infrastructure resides in countries with US foreign military sales (FMS) (e.g. Korea, Taiwan). The US avionic display industry should continue application-specific display R&D, and design and develop the displays for the military avionics market by working jointly with the foreign manufacturers. DoD could facilitate this with offsets in the countries with FMS programs.

There are many tangible as well as intangible benefits due to the \$1 billion investment in display S&T over the past 13 years. Industries such as TI have created display product businesses (e.g. DMD). The intangible benefits include development and possession of display S&T expertise in US, training of display scientists and engineers that address the military and avionics display needs.

Honeywell AM LCD Development History

- '83 - '85 - LCD Technology assessment and evaluation of prototypes
- '86 - '88 - 7J7 Contract - AM LCD Product / Technology Development
 - Joint development with Hosiden / Philips
 - Alphasil AM LCD Manufacturing Venture
- '88 - '90 - TCAS AM LCD Certification
 - 1st Military Cockpit AMLCD, F117 Data Entry Panel, 1989
- '91 - Boeing 777 Contract Award
- '92 - Delivery of 777 Engineering Development Units
- '94 - 777 NB - TN AM LCD Production
 - 33 Patents covering the AM LCD Technology developed
- '95 - F16 4x4" AMLCD Production
 - Started 10.4" IPS - AM LCD Development
- '98 - 777 / 737 NW - TN AM LCD Production
 - 10.4" IPS - AM LCD Product Demonstrations
- '99 - Started 14.1" MVA AM LCD Development
- '01 - 14.1" Product Demonstrations
 - Shipped over 11,000 NW AM LCDs for 777 / 737
 - Shipped over 2,000 4x4" AM LCDs for F16
- '02 - 14.1" MVA AM LCD Certification

Honeywell

Aerospace Electronic Systems

10

Figure 15-10. Honeywell Pioneered AMLCD Development for Aircraft Cockpits from 1983-2002.

"We agree the services should be providing seed money to further development of display technologies."
 -- Andy Ahlbum, Chief, Acquisition and Technology Branch, Warner-Robins Air Logistics Center

16. **Michael Kalmanash (Kaiser Electronics, A Rockwell Collins Company):**
"Head-Down and Helmet-Mounted Displays for the F-22, F/A-18E/F, and F-35 Cockpits"

Avionics head down display (HDD) technology is in a state of flux. The transition from CRTs to flat panel AMLCDs was rapid (some might say *too* rapid), and provided previously unmatched levels of performance and reliability. It quickly became apparent, however, that the first business model [standalone manufacturing of fully-custom AMLCDs] was not an economically viable proposition. In quick succession, "glass" suppliers OIS, ImageQuest, dpiX/Planar and Litton exited the field. Delivery of airplanes was threatened.

Today the supplier situation has stabilized. The current business model is that of a strategic relationship with a large Asian AMLCD manufacturer, who provides specialty panels to meet specific (relatively high volume) avionics needs, using standard COTS manufacturing processes. Ruggedization is carried out either by a third party or a system integrator.

As viable as this situation appears to be, it does not address the needs of all avionics users. As Dr. Hopper and Major Desjardins¹⁴ have pointed out in a series of studies of the military display market, there are many platforms calling for unique displays, that simply do not have the volume to justify this approach. The choice is to change airplanes or change the display technology approach.

The FA-22 faced this issue when "glass" for its 8 x 8 in. active image area Primary Multifunction Display (PMFD) became unavailable following the collapse of OIS. The choice in this program, and almost simultaneously in the F/A-18E/F program, was to opt for high performance rear projection displays using COTS reflective liquid crystal on silicon microdisplays. The commercial applications for high-resolution rear projection systems are mushrooming, and key components are now widely available from a number of suppliers. A common optical engine was developed for the 6.25 x 6.25 in. image area display F-18 projector and the 8 x 8 in. FA-22 projector. Both systems are now in initial production.

The F-35 represents a logical next step in the evolution of display technology. It utilizes a large area (20 x 8 in.) projector to provide a panoramic display surface with an integral touch screen. While direct view AMLCDs continue to improve, and offer advantages such as minimum depth, there is a growing role for versatile high performance projection displays in a variety of DoD applications. The F-35 instrument panel is pictured in Figure 16-05.

Helmet mounted displays are evolving rapidly, and are expected to replace HUDs in a number of aircraft, notably the F-35. The trends are toward binocular operation, day and night operation, ejection safety and reduced weight and power. "Solid state" microdisplays are replacing miniature CRTs, improving reliability and performance reducing weight and cost, and enhancing ejection safety.

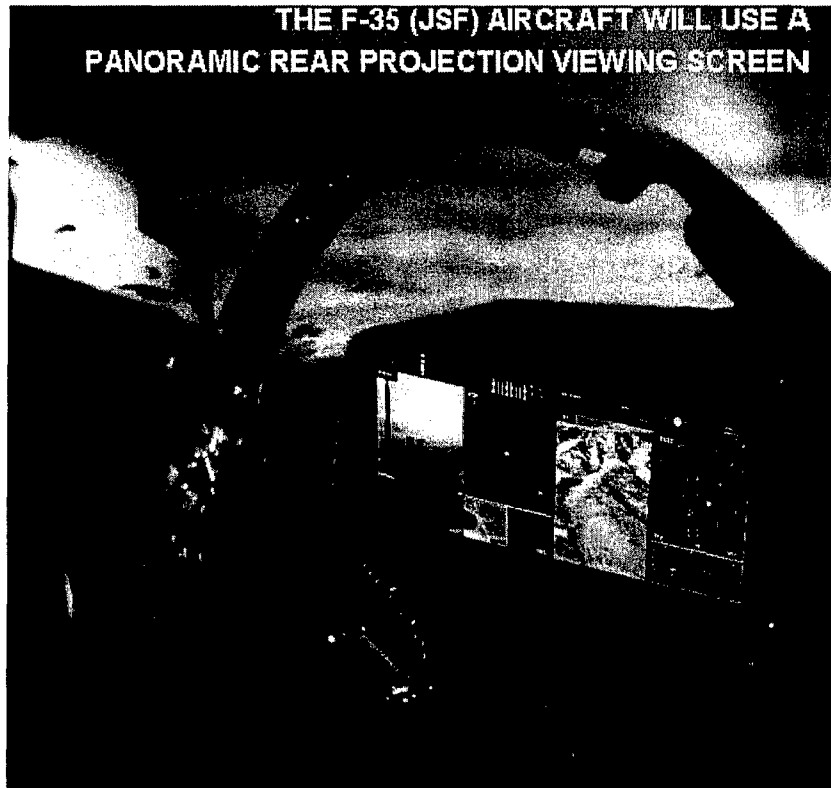
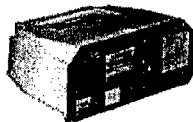
¹⁴ Daniel D. Desjardins and Darrel G. Hopper, *Military Display Market: Third Comprehensive Edition*, AFRL-HE-WP-TR-2002-0139, August 2002, 594 pp. See Appendix C for a synopsis.

**Rockwell
Collins F-35
Instrument
Panel System
Features**

**Large Area:
20 x 8 in.**

**High
Resolution:
2560 x 1024
color pixels
(dual SXGA)**

**Integral
Touchscreen**




**THE F-35 (JSF) AIRCRAFT WILL USE A
PANORAMIC REAR PROJECTION VIEWING SCREEN**

Figure 16-05. Large Area "Panoramic" Tiled Rear Projection Cockpit Instrument Panel for F-35.


HELMET MOUNTED DISPLAYS (HMDs)

Fixed Wing HMD Systems are developed under the aegis of
Vision Systems International (VSI): A Joint Venture between Rockwell Collins and Elbit Systems




JHMCS HMD


- Common System Across Multiple Platforms
- Monocular, 20° FOV HMD




F-15




F-18




F-16



F-22



- Under Development for F-35
- WFOV, Binocular, Day / Night HMD



F-35 HMD

Figure 16-10. Kaiser Leads HMD System Development for Key DoD Combat Aircraft.

17. **Carl Vorst (Boeing): "Technology Challenges in Advanced Simulation Displays"**

Mr. Vorst focused on the display needs of the advanced military simulation community but noted that the basic principals apply across the board. Historically, display component and system vendors have been quick to hawk their product as the end all for all applications. The truth is that there is no one product or approach that is the panacea for all problems. The only way to assure that the right display solution is chosen is to understand the application. The purpose of this presentation is to help the technology selection discipline understand some of the selection criteria and the nuances of current and emerging display technologies, and to point out emerging technologies that are worthy of investment.

Commercial flight simulation is centered on performance specified in FAA Advisory AC-120-40B, which presents a consistent set of requirements for out-the-window display systems centered about representation of weather effects, depicting precision airport lighting patterns and the associated requirements for making low-visibility approaches. Military training requires a whole new set of requirements, mostly added to that for the commercial world, except the requirements may differ widely based on the aircraft platform. Vehicle development simulators require a bright display system that is low maintenance, with moderate image resolution. Fixed wing air superiority fighter trainers require the capability to display high-resolution air targets, while ground attack requires high detail representation of ground targets that blend into the background. Rotorcraft needs center around having a high-resolution view of ground textures, including the periphery, and a high-resolution presentation of threats.

The military simulation community is impacted by a number of issues, including: insufficient funding, limited building space and systems, and unique requirements related to the new emphasis for mobility brought on an event driven change in the way this country must defend itself. This presentation examined a number of technologies and summarized their application to military simulation. Several technologies that show promise in overcoming the shortcomings of popular consumer technologies were summarized. They also have the potential of offering a leap forward in performance and in simulation capabilities. Recommendations for government investment in these areas were presented.

Mr. Vorst noted the simulation community has for decades had an unrealized dream of a full field of view, high quality collimated display that multiple pilots can view seated side-by-side or front-to-back. This dream faces severe technology challenges in display devices, optics, screen, and electronics. An assessment of the status of display technologies and investment priorities for simulation systems is presented in Figure 17-05-06.

Lastly, Mr. Vorst examined efforts to use HMDs for visual simulation and discussed special considerations that are not issues in the consumer world. No one except DoD is interested in HMD simulation systems. Everyone else, including most within DoD, wants direct-view real-image systems. Problems associated with attempts to build acceptable simulation systems based on HMDs include low resolution, head tracking lag and instability, loss of image detail with head motion, limited brightness and issues related to augmented verses complete virtual reality are some of the tasks left to the military world. The dilemma is that, with limited funding, technical expertise, and a limited market, the requirements are still expanding. There are a number of fallacies out there regarding the usefulness of HMDs for pilot training: they are not high resolution, they are not cheap, they are not immersive, their optics will not solve field of view problems, and they will not be ubiquitous with everyone having just because some HMD advocates think they are nifty. Critical needs of HMDs for simulation use include (a) reduced image dwell time to get acceptable dynamic resolution; (b) increased native resolution of display engine; (c) increased horizontal field of view; (d) invention and development of a low-lag, jitter-free head tracking solution.

Simulation Display Engine Status & Investment Priorities

Priority	Technology	CRT	LCD	LCOS	DMD	OLED	Raster Scan Laser	GLV	Beam Directed Light Valve
	Requirement								
#1 -	High dynamic resolution								
#4 -	Night lighting levels								
	Low light point aliasing								
	Matched color gamut								
#2 -	High native resolution								
	Supports calligraphic lights								
	On-screen geom correction								
#3 -	Low transport delay								
	High brightness								
	Advancing technology								
	Consumer applications								

#1- Low dynamic resolution means poor target visibility with rapid ownship movement and the inability to detect motion onset and correctly judge height above terrain and closure.

#2- High native resolution is required to meet target detection and identification criterion.

#3- High transport delay results in simulator sickness.

#4- Poor black level limits ability to properly conduct night training.

Legend:

	It's there
	Pretty good
	A way to go yet
	Doesn't support requirement

Figure 17-05-06. Boeing Assessment of Status of Display Technology Needs for Simulation.

18a. *Raymond L. Liss (Rockwell Collins): "Role of the United States Displays Consortium (USDC)" (Edited by both Mr. Liss and Dr. Robert Pinnel, CTO of USDC)*

Mr. Liss of Rockwell Collins is presently the Chairman, USDC Military & Avionics Users Group (MAUG). The USDC mission is to support member companies and affiliates to build a world class, competitive, U.S.-based display industry. The USDC role is to work industry strategic planning and standards issues and to fund supply chain R&D efforts on behalf of its manufacturing members, government, and military/commercial users. USDC display manufacturing members are Cambridge Display Technology, dpiX Inc., Displaytech, DuPont Displays, E-ink Corporation, eMagin Corporation, FlexICs, iFire Technology, IBM Corporation, Kodak, Microvision Inc., Philips, Three-Five Systems, Versatile Information Products, and Universal Display Corporation. The USDC MAUG and CUG (commercial users) membership is comprised of Barco, Boeing, General Dynamics, Honeywell, Interface Displays & Controls, In-Focus, Kaiser Aerospace & Electronics, L-3 Communication & AMI, Lawrence Livermore National Laboratory, Northrop Grumman, and Rockwell Collins. USDC also has over 60 Sustaining Member companies who are providers of equipment, materials, components and services to the display manufacturing industry. This membership group includes both domestic and foreign companies. USDC gets its R&D program and operating funds from the federal government via an Army

S&T budget line and from member dues. The USDC program encompasses five areas of activity: manufacturing equipment, materials, components, modeling, and applications studies.

Historically, projects have focused on the manufacturing needs of the most common direct view display technology types (including LCD, EL, PDP, FED, OLED) and also projection and microdisplays. As of February 2003, USDC had defined and scoped 96 technical development projects: 56 have been completed (projects fully paid); 27 are in progress; and 11 are under active solicitation or are being defined in preparation for issuance of a USDC request for proposal (RFP). Current technical programs are focused primarily on materials, equipment and components for OLED manufacturing, especially on flexible substrates in support of the Army Flexible Displays Initiative, and on high resolution displays, projection and microdisplays, and military display applications studies such as life cycle cost modeling, high intensity flat backlight lamp, and commercial AMLCD ruggedization. Funding for most of these projects involves cost sharing between USDC and the selected performing organization. USDC members are not, in general, eligible to bid for these projects. Projects are reviewed and approved by the USDC Governing Board after technical review and recommendation for support by the USDC Technical Council. Teams of institutions (one or more) then execute the projects and provide a prototype tool or material samples, a report and briefing to USDC members.

Members of USDC provide guidance on industry/government projects and funds, lead project teams that beta site equipment, test and evaluate materials and components that are developed, and interact with commercial and military display customers. The USDC members receive from the organization translations of major industry documents (technical, marketing, business documents produced by Nikkei Microdevices, Fuji Chimera, InterLingua, iSuppli and DisplaySearch). Members also participate in annual technology workshops (currently Flexible Microelectronics and High Resolution displays), investors conferences, and gain international access through agreements and events with Japan, Korea, and Taiwan. Members also participate in the development of an industry roadmap, which defines the status, issues and trends for all the display technologies from technical, business, market, and applications perspectives. The most recent edition was issued in January 2003.

18b. *Raymond L. Liss (Rockwell Collins): "Rockwell Collins Display Approach"*

Mr. Liss discussed the background and a successful model for AMLCDs and projection head down displays pursued by Rockwell Collins in defense applications and provided some recommendations. Rockwell Collins also produces Head Up displays for military and commercial markets and Helmet mounted displays for military applications.

Rockwell Collins is a world leader in communications and aviation electronics for military and commercial applications worldwide with about \$2.5B sales in 2002. Rockwell Collins business is 55% commercial (air transport, business, in-flight entertainment, regional) and 45% military (communications, displays, integrated applications, navigation) in FY 2002. Displays are about 20% of military sales. Kaiser Electronics, Kaiser Electro-Optics, and Flight Dynamics are subsidiaries of Rockwell Collins.

Core capabilities are communications, displays/surveillance, automated flight controls, navigation, aviation services, in-flight entertainment (IFE), integrated electronic systems, and information management systems. Communication moves information to the people that need it—pilots, air traffic control, and warfighters. The communication trends are high-resolution imagery, sensor evolution, digital databases, global air traffic management (GATM), and sensor fusion-enhanced situational awareness.

Displays are one of the common elements of communication. Tactical and Transport aircraft, both Fixed Wing and helicopter, require head up, helmet, and/or head down displays to support many

existing applications and the trends towards the digital battlefield: radars, forward-looking infrared systems (FLIRs), video and photographic imagery and intelligence, threat warnings, flight instruments, tactical information, synthetic and enhanced vision systems, navigation, 3D situational awareness, digital maps, data links and information networks. Many Military as well as commercial aircraft applications require Federal Aviation Administration (FAA) DO-178 certification. A history of Collins electronic displays is illustrated in Figure 18b-12.

The Rockwell Collins Display Center is the organization within Rockwell Collins that provides a focus and consolidates the common needs and requirements of the Rockwell Collins Government Systems and Commercial Systems business unit, which includes Kaiser and Flight Dynamics. Kaiser Electronics, a supplier of Tactical Head Down, Head Up and Helmets, including the Comanche and JHMCS is a part of the Rockwell Collins Government Systems Business Unit. The Display Center operates under a Center of Excellence Approach and in addition to the Business Units, interfaces to the five key production and development elements: Sharp Corporation for avionic-grade and custom AMLCD manufacturing, the Rockwell Collins Advanced Technology Center for systems technologies, the Rockwell Science Centers for basic materials, optical and displays research, the Rockwell Collins manufacturing operations for production, and finally to other strategic suppliers. The Display Center provides the long-term commitment and infrastructure necessary to support the needs of customers for the entire Rockwell Collins Enterprise.

Rockwell Collins uses Sharp Corporation to manufacture its AMLCDs. Sharp uniquely provides Rockwell Collins "Avionic Quality" (ruggedized design) AMLCD cells. Sharp Corporation is Rockwell

History of Collins Electronic Displays

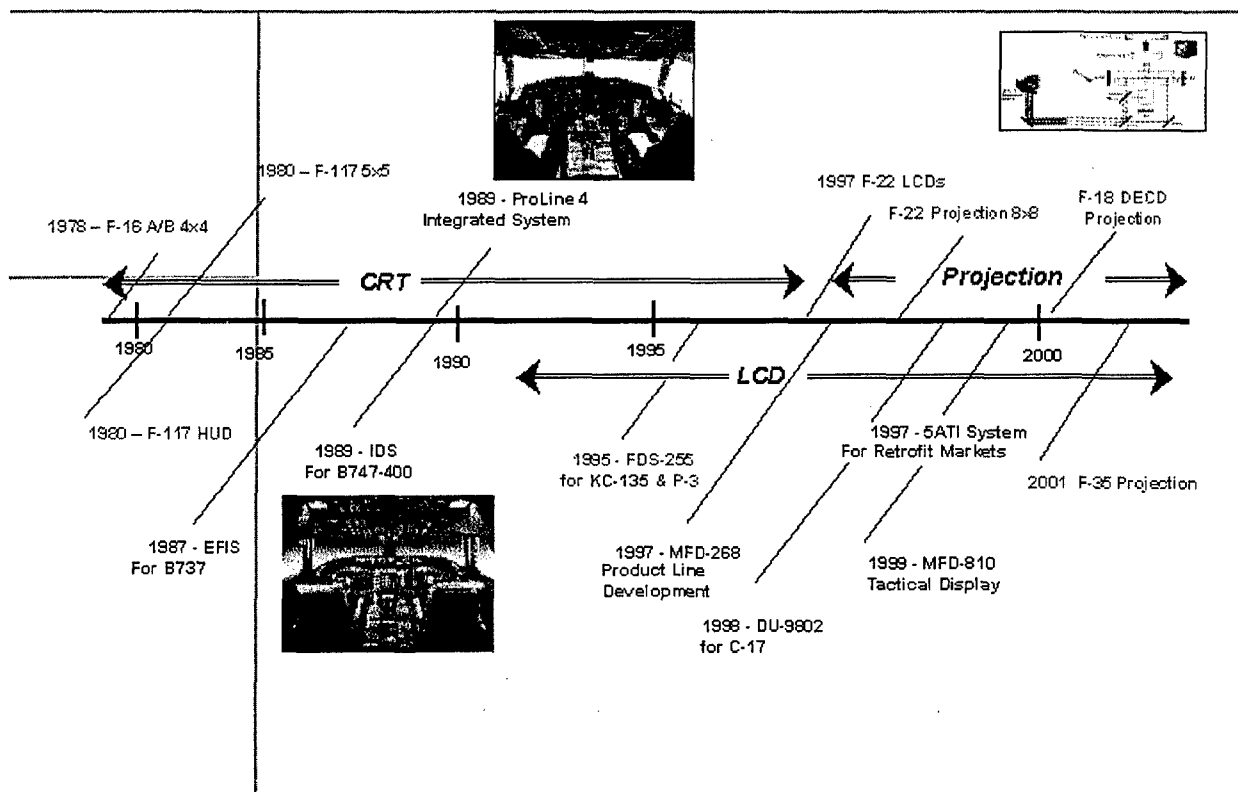
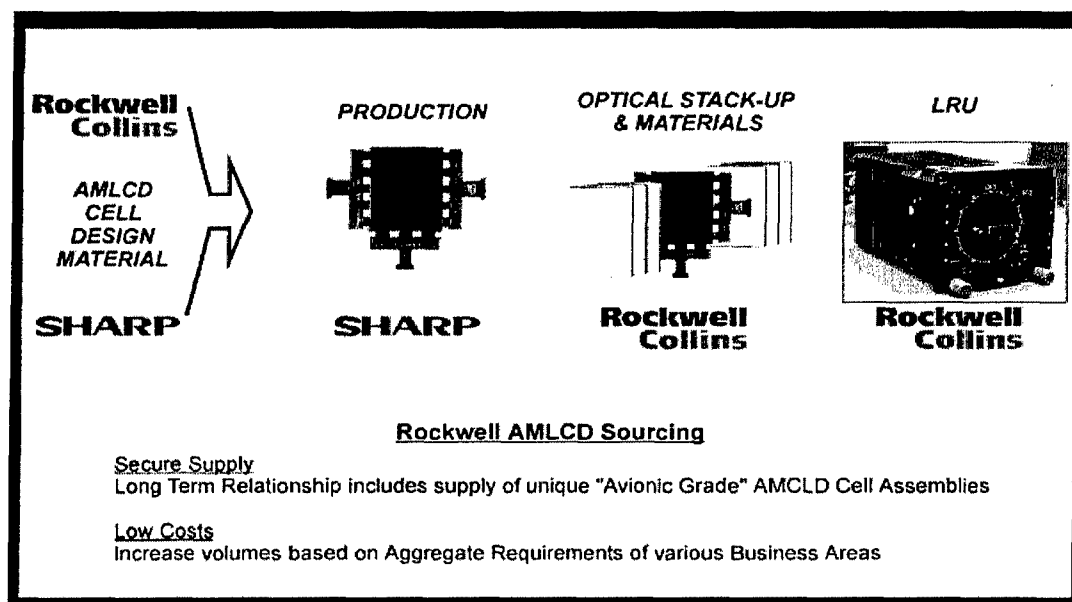


Figure 18b-12. History of Collins Electronic Displays from 1978 to Present.

Collins's primary source of AMLCD cell assemblies based on a corporate technology alliance that has existed over 30 years. The Rockwell Collins-Sharp LCD technology Alliance started in 1991. Regular meetings (annual executive; quarterly coordination) are held to preserve the relationship. Rockwell Collins works with Sharp Corporation to create custom designs with unique sizes, materials, LC fluids, interfaces, resolution, and pixel patterns for avionics applications. Sharp will exclusively build these designs for Rockwell Collins. All glass is produced on Sharp's standard commercial production lines and processes, which are highly automated, to ensure economies of scale, quality, and consistency. Sharp maintains state-of-the-art AMLCD manufacturing processes and facilities, and is continuously investing in new plants and facilities. Rockwell Collins provides application-specific packaging and optical production in the US. Rockwell Collins guarantees availability of glass for 20 years; this guarantee is backed up by a combination of yearly quantity buys and a safety stock. A breakdown of tasks performed by Sharp and by Rockwell Collins in the course of producing AMLCD cockpit displays via their sourcing alliance is illustrated in Figure 18b-15. Sharp has been a reliable supplier of custom avionics AMLCDs to Rockwell Collins. Over the period of this relationship, no deliveries of displays have been missed due to AMLCD supply issues.

Supplier management of critical components in avionics displays goes beyond the AMLCD manufacturer: backlights, graphic engines, processors, specialty components, projection engines, and light sources are also must be monitored and intensely managed. A product line approach for line replaceable units (LRU, installable avionics displays) is taken to allow customers to take advantage of investments and existing product at minimal cost. This approach requires that customers sometimes re-evaluate their requirements—not reduce their requirements to maximize their value. The production line approach enables maximum reuse where it makes sense (common fielded units enhances logistics). And support point solutions where it makes sense. Rockwell Collins borrows many attributes from

Rockwell Collins / Sharp Corporation Avionic Grade AMLCDs



*Rockwell Collins AMLCD Sourcing Alliance
Has Never been the Cause of A Late Delivery*

Figure 18b-15. Division of Labor in Rockwell Collins Sourcing Alliance with Sharp in Japan.

commercial procurement practices, and provides warranties allowing economical and predictable long term support over the life of military programs. This commercial frequently includes an obsolescence management plan that is paid for by Rockwell Collins. Under this approach, Rockwell Collins often pays for the costs of managing obsoleting parts (AMLCD Drivers, electronic components, processors etc) and the costs associated with redesign.

Rockwell Collins is a leading supplier of AMLCD-based avionics displays; products are illustrated in Figure 18b-18. Annual unit sales have been typically 17,000 units for cabin entertainment systems (6.4, 8.4, 10.4 in. sizes). Cockpit display sizes (annual unit sales) are 3ATI (2200), 5ATI (2000), sum of 5.0 and 5.6 in. (700), 10 in. (1000), ARINC "D" (360), and 13.3 in. (200).¹⁵ Rockwell Collins leverages applied technology and investments across markets to reduce development cycle time, enhance the technology base, and lower total cost of ownership. Rockwell Collins head down display product lines are on dozens of platforms worldwide: nine types of military helicopters; eleven types of military transports and tankers; five types of fighter/attack aircraft, and nine types of commercial and general aviation aircraft. With a mature and evolving product line, these platform quantities are growing annually.

Mr. Liss emphasized the criticality of DoD research funding. Internal R&D funding in industry is shrinking and corporate technology centers are being eliminated. Corporations are demanding shorter term return on investments (ROIs). Mr. Liss suggested that DoD needs to steer industry to its requirements and continue investing research funding. Also, DoD advance development funding will be required for the specialized, comparatively low (compared to commercial applications) quantities typical

Rockwell Collins' AMLCD Product Lines

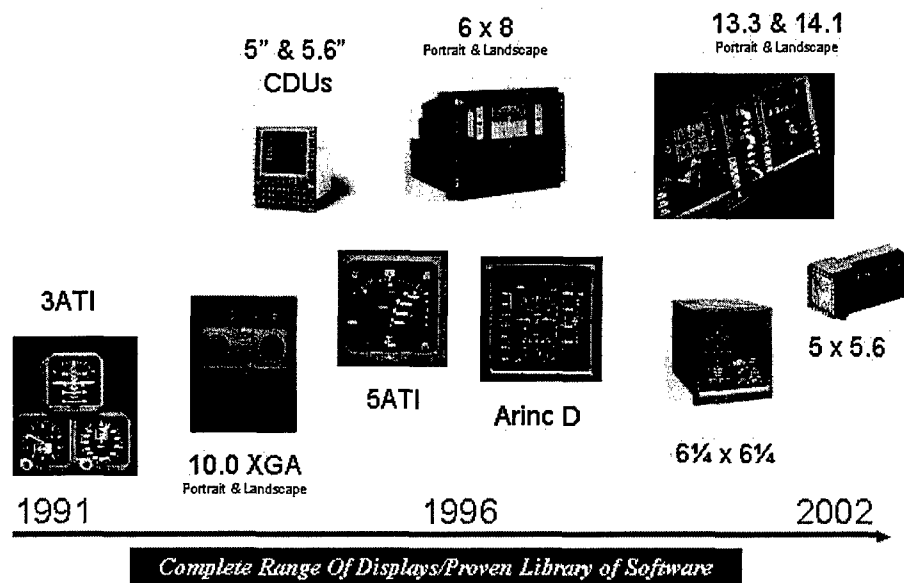


Figure 18b-18. Rockwell Collins Cockpit Display Line Replaceable Units.

¹⁵ The commercial avionics sizes 3ATI, 5ATI, and ARINC "D" refer to instrument panel footprints of 3x3, 5x5 and 8x8 in., respectively; viewable display area is less. The other sizes refer to the diagonal of the viewable area.

of military applications. Academia will also require specific guidance on new government technology needs. Technology demonstrations will often require government funding. Ample time should be anticipated to properly install and integrate a new technology in air or ground platforms. Ultimately, with judicious and sound investments, significant benefits, including shorter development cycle times to the DoD, and ultimately the warfighter can be achieved for these new technologies.

Mr. Liss suggested that the role for DoD S&T community is to (1) translate military doctrine, concepts of operations, and requirements for industry and academia; (2) understand capabilities of the supplier base on all critical technologies and work independently with integrators who possess the relationship; (3) serve an advisory role to programs and technology; (4) continue investment strategies with guidance of future roadmaps; and (5) monitor and advise industry on enabling technology and interfaces such as sensors. Technology can be fielded in a balanced and efficient manner by coordinated use of DoD S&T, Industry and Academia. Military doctrine is the fulcrum that balances academia and industry activity on the one side with US DoD S&T interests on the other. Benefits of technology awareness and insertions may include operational enhancements, Total ownership cost improvements at the LRU and Vehicle level, vigilance for component obsolescence, and ultimately economical aircraft/vehicle service life extension.

Display technology development can be looked at in three waves. Near term development (1-3 years) in displays should focus on critical technology needed to feed existing production programs, accelerate implementation into production, and implement new concepts of operations, display materials, and processes. Some current display technology needs are: display materials, large tiled displays, small displays, OLEDs, flexible displays, sensor technology, sensor fusion, enhanced and synthetic vision, data fusion, wireless communications, uninhabited aerial vehicles (UAVs), data links, bandwidth limitations, LRU integration, software automation, and laser protection.

Mid-term needs (3-10 years) are research that will enable 3-10 year time frame technologies, display technology prototyping, and developing operational concepts and military doctrines for new technology. Specific mid-term needs are conformal cockpits, new display technology (processes, materials, optics), data fusion, augmented reality, human absorption of data, and artificial intelligence.

Long-term needs (10+ years) and concepts require basic research and validation to allow for envisioning and interpreting military doctrines for new future technologies. Specific long term needs include flexible pixel formats, 3D volumetric displays, covertness concepts, human adaptation to new technology, full immersion displays, and multi-sensory displays. Some current and future cockpit display technology needs are illustrated in Figure 18b-34.

Mr. Liss concluded by stating that Rockwell Collins has delivered over 8,500+ military displays in the past 6 years and is bringing DoD the next generation of displays via projection technology in selected sizes on the F-18, F-22, and F-35. He stated that market conditions and logistics requirements have forced acquisition reform, innovative sourcing, and product line approaches. Industry is always challenged to understand the military's needs. Military applications will be a driver to future display technology. However, as demonstrated with Rockwell Collins' arrangement with Sharp Corporation, future military displays will most efficiently be adapted from current commercial technology due to mass production and huge investments by the commercial sector. DoD S&T should distill military doctrine and requirements. Government will then need to invest in relevant development and adaptation to assure DoD gets the technologies and products it needs in the timeframes required.

Cockpit Displays Technology

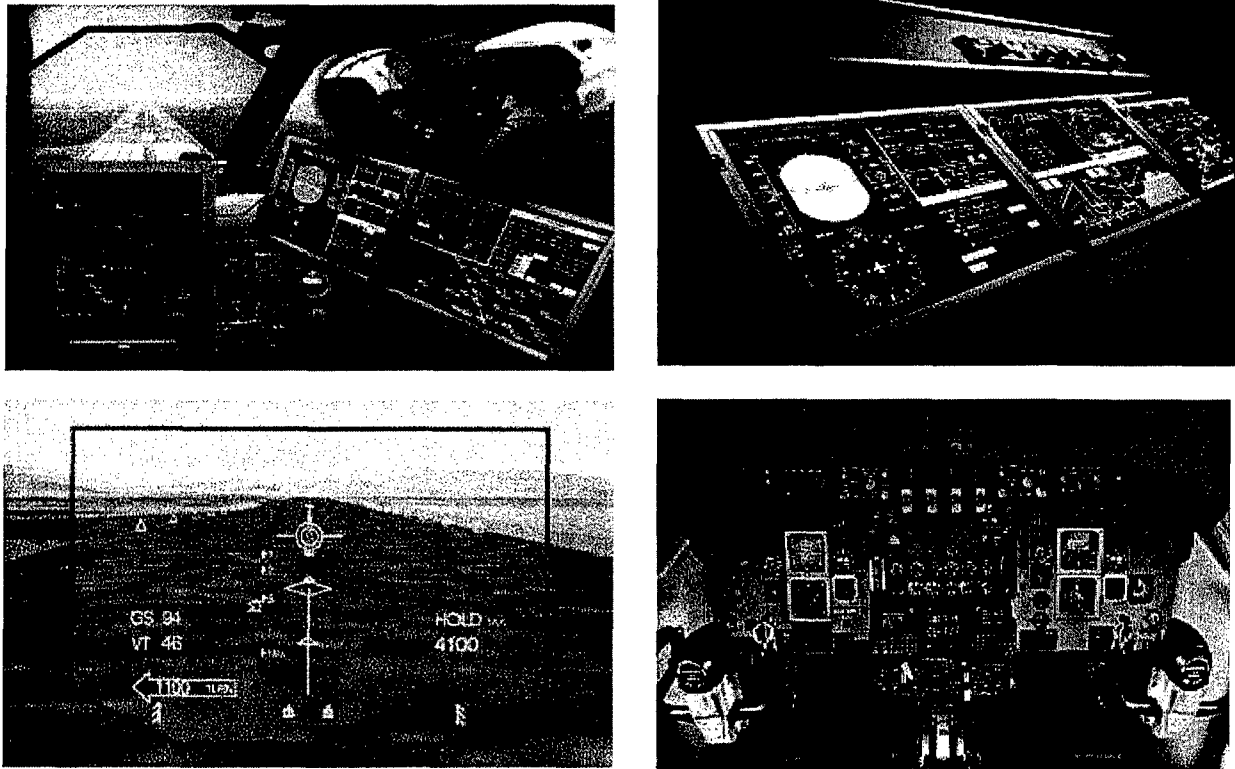


Figure 18b-34. Rockwell Collins Cockpit Display Systems.

19. Mr. John Thomas (General Dynamics Canada):
"Land & Sea Systems (Abrams, AAV, DD21, subs)"

Mr. Thomas noted that General Dynamics (GD) is a defense company employing 44,000 people and generating ~\$10B in annual sales. It is dominant in ship/submarine building, land and amphibious combat systems and a major player in military information systems. GD is a platform integrator, supplying systems to the DD21 destroyer (Bath Ironworks), Ballistic Missile submarines (Electric Boat) and notably, to land vehicles such as the M1A1 and M1A2 Abrams, as well as to the new AAV vehicle (Land Systems). General Dynamics also supplies guns (Armament Systems, etc.) and is a dominant player in surveillance and reconnaissance systems and to the digitized battlefield. At General Dynamics, information technology is seen as a critical element in achieving dominance of the future battlespace. The existing battle space as a poorly communicating entity. The vision is to apply networked information technology to battle space management. Information is useless without displays – the primary means of data input for humans is visual.

Unmanned or robotic vehicles will also require displays, since a primary function of these systems will be provision of reconnaissance data. General Dynamics sees an increased need for specialist reconnaissance/surveillance vehicles with several sensor types and for fully immersive armored vehicles used in the projection of manpower into the battlefield. For foot and for vehicle-borne troops, there is a

need for soldiers to view the path forward over hostile territory, using a fully fused data set including visible, infrared, and radar imagery with threat data. In all cases the data need to be available via smart displays able to zoom into resolutions providing a "virtual walk" to the objective. Displays are universally necessary for these visions to become reality.

General Dynamics and its divisions currently dominate in supplying land-vehicle systems to the Army. The current situation sees a mix of minimally integrated displays in specialized applications. Little attempt has been made to rationalize acquisition with commonality. Data busses are last-generation types and video is distributed via analog interfaces. Mr. Thomas described the need for future ground vehicle displays. The future of land-vehicle displays should involve hardware commonality and open architectures. Both elements are key to achieving affordable system improvements. Commonality can be achieved only by aiming for higher performance. Displays should provide more resolution than required by the simplest functions to facilitate cross-functional flexibility. Functional flexibility means the same display is used across vehicle functions and locations, and is shared, for instance, with dismounted portable functions including TAD, maintenance, and individual situational awareness. The General Dynamics vision for new vehicle displays includes in-built processing with fast data busses and optional wireless access. There is a need for improved performance in areas such as faster video response, higher luminance, better viewing angles and improved touch and voice I/O operator interfaces. These displays must consumer little power and operate over a wide illumination and temperature range.

Mr. Thomas said that ruggedized COTS is seen as the only safe way to provide affordable land-vehicle displays for the Army. Unmodified COTS represents unacceptable personnel risk and custom displays are too expensive. The display acquisition strategy for DoD land vehicles must be realistic in that it accepts certain limitations along with the advantages of COTS components. Unmodified COTS has insufficient performance, severely limited supply stability, and presents a critical risk level to human assets. Ruggedized COTS is a proven minimum-cost acquisition solution but has life cycle cost risk as commercial products come and go rapidly and without warning. Semi-custom COTS (custom format hardware from a COTS source) is not cost effective in land vehicles; it is necessary for high performance applications only. Full custom displays (custom format hardware obtained from a lower volume source specializing in military components) are justifiable only for special formats such as Gen-2 FLIR. Semi-custom and custom are both subject to single-source survival and cost implications, though this risk can be reduced with long-term relationships between military display integrators and display manufacturers.

The role of the DoD S&T community is to act as an essential broker between user and industry, setting expectations and motivating appropriate academic research. The DARPA administered Technology Reinvestment Program (TRP) program was a success, providing displays such as the FLIR display to the Abrams SEP. We need to repeat this type of program as we move forward into the exploration of new systems solutions. COTS displays have been successfully applied to Abrams, Bradley and now, the AAAV platforms. A new generation of improved COTS based displays will be required as commercial offerings move rapidly to new products offering enhanced characteristics. COTS based displays cost less in acquisition, but Government needs to recognize that this is only part of the advantage. COTS displays offer DoD the prospect of rapid evolution and improvement in military effectiveness if full advantage is taken of the rapid advances in COTS based technology.

Mr. Thomas said GD believes that past DoD S&T display investment has been largely effective and definitely successful. It has been funded at less than 1% of the Japanese investment alone and has provided U.S. forces with the most sophisticated and effectively connected/informed army in the world. Past DoD investments in displays have paid off in fielded systems. These investments have created knowledge on how to utilize offshore sources for both COTS components as well as for customization into "semi-custom" displays. These investments have educated industry to a point where it can mitigate risk in critical offshore sources. Blind alleys such as the field emission displays (FED) and polyplanar

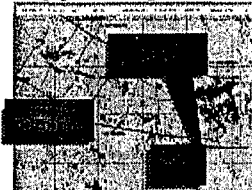
optic display (POD) are inevitable; DoD should learn to assess commercial viability and cut losses in order to re-invest in technologies that become commercially viable.

DoD should also judge the value of its investment in on-shore display knowledge gained by its military integrators through acknowledgement of what are clearly world-leading capabilities. Compared to Japanese investment in AMLCD, the DoD investment is miniscule (<1%), but despite this, DoD fields the most information-centric forces. A specific past success cited by Mr. Thomas was the DARPA Technology Reinvestment Project (TRP) that produced the current generation of custom EL display technology used in vehicles such as the Abrams for monochrome FLIR video. The TRP project provided essential impetus for advanced high resolution video EL displays; these displays are inherently rugged and survivable, are in service now, and well-liked by the user community. Related and derivative EL displays being provided to various DoD platforms, promoting commonality of technology and components. The TRP program is a successful example of government support to provide an optimum technology to the military.

Near-term investments specifically recommended by Mr. Thomas include planning an upgrade path involving rapid prototyping to address the limited supportable life for COTS-based display programs such as Bradley and Abrams. Also, proving of OLED technology in a military setting, improving touchscreen technology, developing methodology for applying voice I/O to displays, and selection/standardization of a video rate data bus for vehicles were recommended.

Battlespace Integration Vision

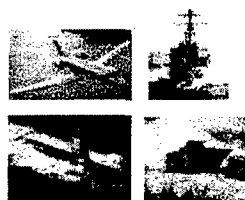
Decision Support Systems



Sensor Systems



Within Platforms



Life Cycle Support



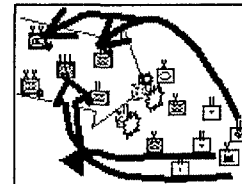
Within the Battlespace



Collaborative Command and Control



Computing and Communications Networks



Understanding information requires displays

Figure 19-08-10. General Dynamics Vision – Information Superiority Will Dominate Battlespace

Mid-term investments suggested include proving of flexible displays in land-mobile environments, definition of a new range of "smart" displays with processor, provision of advanced graphics and zoom engines with overlay, and improved commonality across programs and systems.

Far term (10 to 25 years) investments suggested are implementation of totally immersive environments to facilitate robotic systems, possibly integrating displays with tactile feedback, display resolutions meeting human eye limitations, and high data rate networked intelligent display systems with wireless connectivity at subsystem levels.

The role of DoD's S&T community should be to bridge the gap between users and Industry as an honest broker, to seed new technologies (expert assessment of promising new technology resident in Industry), to provide Industry with insight into military display operational requirements, to set display performance expectations for programs, to interpret effectiveness through logistical data, to promote rapid prototypes for new systems proving, and coordinate industry and academia in forward planning.

DoD must address several on-going display issues. First, DoD S&T agencies must lead the search for new technologies; it must seed promising technologies, support rapid prototypes to prove system & display concepts, and implement technology demonstrations in industry. Second, DoD should implement a policy to minimize type proliferation; further, encourage all display acquisitions to be made on a justified life cost basis (versus a program by program basis) using LCC analysis made fair through application of a common tool, as developed through USDC under an acquisition reform project. As part of this, DoD should implement a true and detailed display inventory database for identification of "approved" display types for new applications to minimize type proliferation. Third, DoD should assess and conditionally promote on-shore OLED sources, conditional on economic viability with limited volume production. Fourth, DoD should utilize civilian agencies such as USDC to coordinate Industry.

"Display S&T investment by DoD have been less than 1% of the Japanese investment alone and has provided U.S. forces with the most sophisticated and effectively connected/informed army in the world."

-- John Thomas, General Dynamics

20. Al Jackson (Raytheon Elcan):

"Digital Displays (Combat and Training Consoles, Tiled Display Systems)"

Mr. Jackson discussed displays designed and integrated by Raytheon ELCAN based on the Texas Instruments (TI) Digital Light Processing (DLP) technology. The heart of DLP technology is a light engine comprising a MEMs technology, TI digital micromirror devices (DMD), integrated with an optical system and screen. Raytheon ELCAN focuses on digital displays in rear-projection designs with high-resolution and size (1280 x 1024 pixels (SXGA), 21 inch diagonal and larger screen sizes. The TI DMD digital light processing technology was developed on a DARPA-funded program managed by AFRL from 1990-1995 and ended with the delivery of a purely digital 2.1 Mpx video system.¹⁶

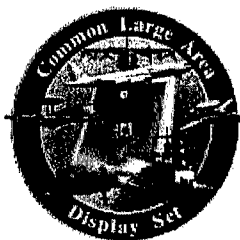
¹⁶ From 1995 to the present TI has structured commercialization agreements with over 40 consumer electronics giants and several specialty electronics companies around the world to bring DLP technology to successively larger commercial markets: presentation projectors for conference rooms beginning in 1996, electronic cinema theatres beginning in 1999, and consumer high definition television monitors in 2002 (introduction price in July 2002 of 1 Mpx unit is falling steadily and expected by TI be less than \$1K by 2006). The DLP-based products are strongly preferred in all of these markets. TI provided this plan at the final review of the DARPA-funded AFRL-managed S&T contract in early 1995 and has met this technology roll-out plan at every point during the past eight years.

In 1996 TI developed a plan to transition its DMD-based DLP technology to military applications and licensed Raytheon to address the defense business. Raytheon is teamed with ELCAN Optical Technologies for the design and manufacturing of the optical subsystem included in each DLP projection light engine. The business plan focused on sensor stations, map tables, C4ISR workstations, and command centers. The DMD chips and DLP light engines used are based on the commercial TI DMD design and production technology, but the military applications get somewhat higher resolution chips and optics system than the main commercial market will support at any given point in time. Raytheon won a competition for a replacement display in AWACS crewstations under the Common Large Area Display Set (CLADS) engineering development program managed by the Warner-Robins Air Logistics Center. Some 1071 CLADS displays are needed: 621 for E-3 Sentry AWACS; 350 for E-8C JSTARS; and 100 for ABCCC pods that are flown on EC-130E Hercules. Consoles in several AWACS aircraft (14 per shipset) have now been upgraded with the Raytheon ELCAN 21-inch diagonal Digital Rugged Display (21DRD) and are in regular service. The crews strongly prefer the DMD image over the CRT it replaces.

A 32-inch version (32DRD) using the same light engine has been designed and produced for the Navy under its AN/UYQ-70(V) submarine console program for use as a horizontal map table (32-inch) or vertical monitor (32-50 inch). This 32DRD large screen display has been submarine-qualified, including the 15-30 g operational shock test, to meet the requirements for the SSN 774 Virginia Class Horizontal Large Screen Display (HLSD) and Vertical Large Screen Display (VLSD), and for a Navigation Decision Workstation (NDW) for earlier submarine platforms. Under the NAVSEA Computer Aided Dead Reckoning Tracer (CADRT) Program, DRS Laurel Industries used a customized Raytheon 32DRD to produce the CADRT console with a 37.5-inch image for showing navigation and other screens; no degaussing or color adjustments were required as had been the case for other projection technologies based on CRTs and LC Light Valves.

The NASA Virtual Panel Payload Training System (VPPTS) required Raytheon to build an interactive payload rack simulator for NASA-Houston in four months by integrating two of its 32DRD units with a digital video interface (DVI) and touch screen; a seamless display area of 28.5 x 52.5 in. (width x height) installed into the standard International Space Payload Rack; all switches, buttons, small electronic displays, bezels, and imprinted labels in any panel can be simulated under software control to represent any specific payload panel in any of the shuttles, whose configurations vary significantly. An AFRL digital HUD research program with the Flight Vision Division of CMC Electronics is exploring the use of a customized Raytheon projection engine. Raytheon has also installed a seamless 16 Mpx wall video display system comprising 12 of their SXGA Constellation Tiling Units (CTU) in a command center in the Washington DC area. Advantages over other technologies include less than 1 pixel distortion over large projection distance, stable and repeatable sub-pixel precision mechanical alignment, and a level of digital clarity unmatched by any other display technology.

Products based on the SXGA resolution DMDs all have common electronics and common spares. Four products are in volume production: CLADS (flight-qualified), 21 DRD, 32 DRD (submarine-qualified), and Constellation Tiling Units. A 50-inch DMD display is presently being designed for prototyping. The image orientation in the CLADS product for AWACS is portrait; the remaining products are landscape. The viewable image pixel ranges from 300 to 500 μm square (measured at the screen) based on 16 μm DMD pixels (measured at the device). The DLP DMD-based product specification permits 21, 32, 37.5, and 50 in. screen sizes via changes in optics with common light engine components. The 21 DRD performance specification is typical and includes: 40 fL luminance, >500:1 contrast ratio, 24 bit color, 205 W power, 40 lbs weight, and digital and RGB analog interfaces. Transition of TI DMD-based DLP technology to defense and space applications is illustrated in Figure 20-(10,11,25,26) and Figure 20-(13,14,18,20). During the STAR the 32DRD product was on exhibit.

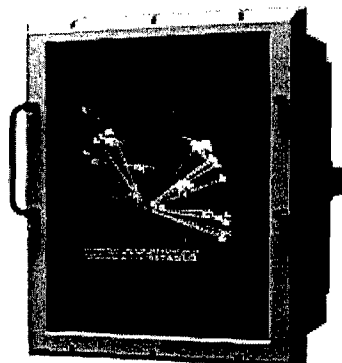


Common Large Area Display Set (CLADS)

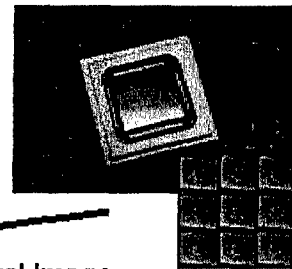
- Form-fit-function replacement for aging CRTs in mission consoles
- 21" digital display using 1280 x 1024 pixel Digital Micromirror Device



AWACS, E-3 Sentry (621 Displays)



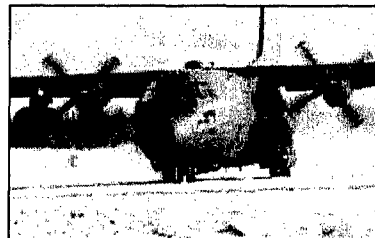
JSTARS, E-8C (350 Displays)



Digital Image

17 micron
Micro-mirrors

ABCCC, EC-130E Hercules (100)



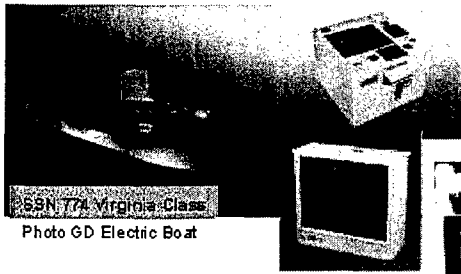
AWACS Operators: "We prefer the clear, reliable digital CLADS DMD monitors over the CRT"

Figure 20-(10,11,25,26). Transition of CLADS to Air Force C4ISR Platforms (Raytheon, ELCAN).

Mr. Jackson provided five reasons to use a DMD-based display rather than alternative display technologies: (1) it looks great (breathtaking SXGA digital pictures on which one can clearly see the finest details of the image sent to the display (lost in other display technologies); (2) it is rugged (testing beyond the extremes of the Arctic and the Sahara, routinely torture tested by baggage handlers); (3) it is versatile (digital, scalable to any size, usable in any environment or application); (4) it is inexpensive to maintain (highly reliable, no maintenance tweaking or adjustments, all maintenance is easy circuit board replacement; and (5) it is in service in the US Armed Forces.

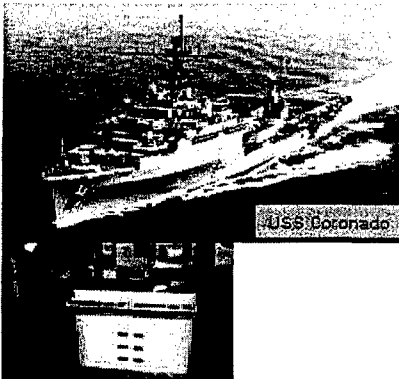
The DMD-based displays are better than CRTs or LCDs because they are inherently more rugged, easier to read, do not smear or retain moving data, do not distort the image, have better color stability, have true display sizing (21-inch size produces a 21-inch viewing area), do not require degaussing, do not have electromagnetic emissions, and are easier to maintain. An example is the display of horizontal and vertical red lines: the typical CRT has an RGB dot triad structure with a fill factor of 20 to 60% for red; the typical LCD has a RGB pixel stripe structure with a fill factor of 12 to 50% for red; but the typical DMD has a fill factor for red of 89%. A photo of a SXGA DMD chip, a micrograph of its 16 um micromirrors is included above within Figure 20-(10,11,25,26).

The DMD works by binary pulse width modulation and operates so fast (pixels can be switched 11,000 times per second) that the greyscale and frame rates that can be rendered far higher than required

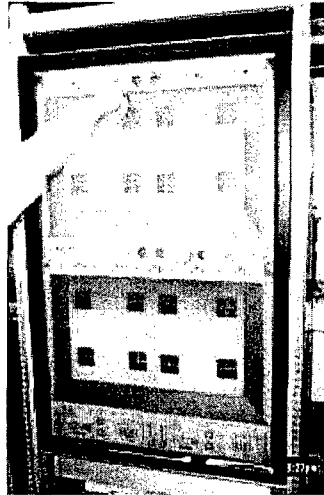


SSN 774 Virginia Class
Photo GD Electric Boat

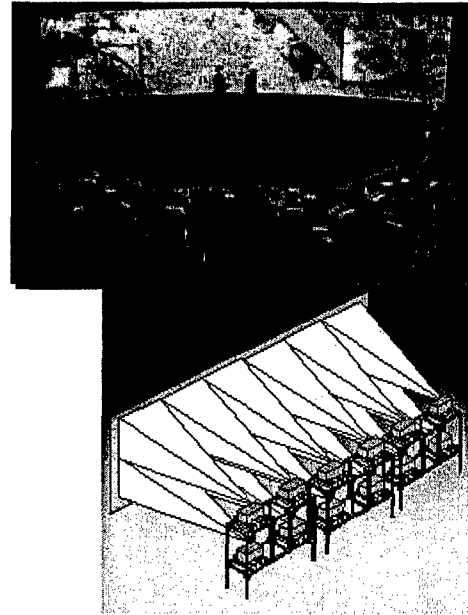
Digital Displays Based on TI DMD



NAVSEA AN/UYQ-70(V)
32-50 in. Large Screen Display
and 37.5 in. CADRT display
for Situational Awareness,
Navigation, Decision Making



NASA 2.6 Mpx Console Comprising
two SXGA 32DRD units for Virtual
Panel Payload Training System



21 Mpx Video Wall
Comprising 16 SXGA
Constellation Tiling Units
for Command & Control

Advantages of TI DLP DMD-based displays cited by users:

- No degaussing required, No color adjustments required
- Digital, Open System Architecture
- Long distance projection with geometric distortion < 1 pixel
- Stable and repeatable sub-pixel precision mechanical alignment

Figure 20-(13,14,18,20). Sea, Space, and Land Applications of Digital Displays (Raytheon, ELCAN).

to be "eye-matched" as defined by Dr. Larimer in his presentation. The video interface supports all industry-standard video inputs (analog RGB, DVI, S-Video (NTSC/PAL), composite RCA (NTSC/PAL), and has multiple synchronization modes (separate horizontal/vertical, composite, green).

Testing has involved over 210 billion cycles of the micromirrors, 20 thousand display system on/off cycles, and two thousand thermal cycles. Accelerated testing indicates that one added defective pixel will occur for every 22,500 hours of operation.

Mr. Jackson noted that over the past 10 years DoD has strongly encouraged the use of COTs components in military solutions. However, Raytheon believes DoD should pursue a COTS-Plus strategy instead. Twenty years ago the 80286 processor had a clock speed of 6 MHz and display monitor resolution was 640 x 480 (VGA). Today processor clock speeds are 2.5 GHz and display resolution is 1280 x 1024 (SXGA). The advancements have been 417X for processors but only 4.2X for displays. The reason given by Mr. Jackson for this situation is that there are no driving commercial demands for higher and higher display resolutions.

Mr. Jackson made three recommendations: (1) display products need firm support from DoD for present and future products; (2) AGED should take an active role in developing higher resolution displays; and (3) projection display producers need support for long life dimmable light sources.

SUMMARY OF RESEARCH PERSPECTIVE PRESENTATIONS

21. **Dr. Robert W. Tulis (DARPA): "Summary High Definition/Flexible Displays Programs"**

Dr. Tulis (a) presented an overview of the last decade of display development covering the High Definition Systems, Microdisplay, and Flexible Emissive Display Programs; (b) summarized the main technical thrust areas over the last three years of DARPA display programs and results to date; and (c) provided a vision of intelligent pixels and the impact on novel digital imaging. Details of this presentation are not available for public release.^{17,18}

22. **Dr. Robert L. Wisnieff (IBM Thomas J. Watson Research Center): "Ultra-High Resolution Displays"**

Dr. Wiesnieff provided details on the high-resolution AMLCD design, application and development to replace desktop CRTs and to provide digital flat panel display technology beyond the capabilities of CRTs. Points covered were the high-resolution AMLCD business, form factor design, key manufacturing technologies, display array design, display module design, digital interfaces, monitor electronics design, and how to drive ultra-high-resolution LCDs. Display technology advancement has lagged behind advances in other commercial PC technologies as illustrated in Figure 22-02. For example, from 1996-2001 the CPU speed increased 13X, memory increased 32X, hard disk capacity increased 60X, communication speed increased 277X—but display resolution increased just 3X from 0.48 Mpx SVGA to 1.3 Mpx SXGA. This situation changed on October 9, 2001 with the announcement by IBM of a 9.2 megapixel, 22-inch diagonal AMLCD monitor, the T221, or Bertha. Bertha is 19X the resolution of the 1996 SVGA, albeit not at video rate due to the lack of high speed high definition driver chips. The pixel density is over 200 per inch, which provides superior text and image quality; even very small point sizes (e.g. 6 point) are clear and legible. Dr. Wisnieff noted that much work is needed at the system level to deliver the bandwidth to ultra-high resolution displays. Software issues exist for all operating systems (OS)—Windows, Linux, and Mac—all of which define icons and fonts based on pixels: resolution independent definitions are needed. Graphics adaptor issues must also be addressed. Each application must be presently be adapted to high resolution; once a fix is done in the OS it should be automatically done in the application. Benefits of the high-resolution T221 TFTLCD (9.2 Mpx, 200 ppi) vs. current high-resolution CRT (2 Mpx, 100 ppi) include: 4.8X the information content (more of the database can be seen at a glance); 4X the areal pixel density (more detail can be seen); 10X lower power per pixel, 30% lower power per display; small footprint and weight; stable color and precise gamma; and digital drive; and less flicker and better pixel definition provide improved user comfort.

The rationale for high-resolution monitors can be provided by looking at routine applications like reading. For normal reading distance a standard, 100 ppi display inhibits reading speed for text in 8 point font; even a person with sub-standard visual acuity of 20/40 can easily read 8 point or smaller fonts in print. Newspapers use 6 point font for sports and financial data. Persons with normal visual acuity of 20/20 can read 4 point letters—the "fine" print in documents, pill bottles, et cetera. A 200 ppi display is needed to support normal visual acuity for reading.

¹⁷ Some results of DARPA funded work are included in this report within the presentation summaries of Calvo, Woodard, Kazlas, Wagner, Liss (USDC), Jackson, Brown, Downing and Larimer.

¹⁸ A 25-page review of the complete FY1989-FY2001 DARPA display program has been published: Robert W. Tulis, Darrel G. Hopper, David C. Morton, and Ranganathan N. Shashidhar, "Review of Defense Display Research Programs," in *Cockpit Displays VIII: Displays for Defense Applications*, SPIE Vol. 4362, pp. 1-25 (2001). Available at <http://www.spie.org>

■ Display technology advancement in the last five years has lagged behind advances in other PC technologies.

	<u>1996</u>	<u>2001</u>	<u>2001 / 1996</u>
■ CPU	32 bit 133 MHz	32 bit 1.7 GHz	13 x
■ Memory	16 MB	512 MB	32 x
■ Hard Disk	1GB	60 GB	60 x
■ Communication	28.8 K bps	8 M bps	277 x
■ Display	SVGA (0.5 M pixels)	SXGA (1.3 M Pixels)	3 x
<p>Will Create New Computer Application !! Same as LCD created Note PC and Cellular Phone</p> <p>2001: 9.2Mpixel = 19 x SVGA</p>			

Figure 22-02. Five Year Technology Development 1996-2001.

Key manufacturing technologies enabling high-resolution TFTLCDs include high conductivity row and column lines, a high resolution process (HRP) that allow vertical layout of data signal lines and indium tin oxide (ITO) so the distance makes wider aperture ratio possible than with traditionally horizontal layout), wide viewing angle via dual domain (m=2) in-plane switching (IPS), video response liquid crystal, post spacer technology with posts built over transistors rather than traditional ball spacers in LC area of pixel, one-drop fill technology for LC (revolutionary decrease in production time and steps), alignment layer without physical rubbing, cell alignment tolerance, and yield management and array testing. The resultant improvements are summarized in Figure 22-15.

Display module design led to a decision to drive the T221 3840 x 2400 pixel format at 41 Hz. The array is segmented into four stripes of 960 x 2400 pixels with dual column drivers at the end of each. The interface to the graphics card is via dual link digital visual interface (DVI) using transition-minimized differential signaling (TMDS) running at a maximum bandwidth of 5.38 Gbps on CMOS/TTL chip technology. Digital PV Link is the next generation protocol. Digital display interfaces have several advantages over the analog interfaces now commonly in use for monitors: cost reduction; less susceptible to noise; easier clock recovery; synchronization between multiple digital links with separate clocks possible and much easier; new protocols such as Digital PV Link enabled; and "digital" has a strong marketing effect. Monitor electronic design and driving schemes from personal computers were also described. One of the IBM T221 Bertha monitors was on display in during the STAR.

T-221 Flat Panel Monitor Defines The State of the Art

IBM High Resolution Process plus In Plane Switching
Reduced Transistor Footprint and Alignment Issues and
Enabled Both High Pixel Density and Aperture Ratio

Image Size: 22.2 in. (478x299 mm)

Addressability: 3840 x 2400 pixel

Colors: up to 16.7 million (24 b)

Frame Rate: 41 Hz

Luminance: 235 cd m⁻²

Contrast Ratio: 400:1

Viewing Angle:

±85° up, down, right, left

Weight: 12 kg

Power: < 150 W (typical)

Signal: 2 DVI

Operating: 0 - 35°C, 8-80% RH

Storage: -20 - 60°C, 5-95% RH

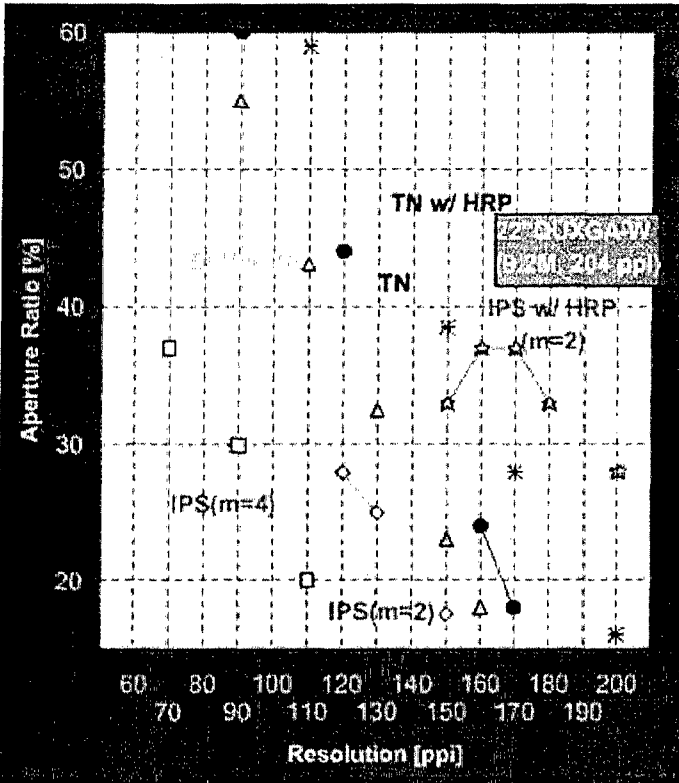


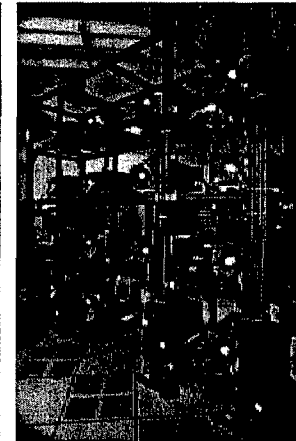
Figure 22-15, T221. T221 Enabled by Simultaneously High Aperture Ratio and Pixel Density.

23. Dr. Philip D. Heermann (DoE Sandia National Laboratories): "Massive Scientific Visualization"

Dr. Heermann noted that the Department of Energy's (DoE) Accelerated Strategic Computing Initiative (ASCI) has pushed large computer platforms to compute capabilities beyond 10 TeraOps/sec. These large machines produce simulation results that exceed 1 Terabyte. Visualizing these data sets is a significant challenge. Sandia National Laboratories (SNL) has developed large pixel count display systems and commodity computer clusters to address data exploration of these massive data sets. The SNL current state-of-the-art display is 60 million pixels (Mpx) driven by a rendering cluster that has demonstrated rendering rates of 300 million polygons/sec. These figures contrast with 2.4 million pixels delivered performance on the current single pipe supercomputer rendering system and rendering rates of 24 million polygons/sec on multi-pipe supercomputer graphics systems. The 60 Mpx display system is illustrated in Figure 23-10-20.

The presentation covered the simulation data of interest, Sandia's approach to visualization, and the present rendering and display systems. Also, Dr. Heermann discussed the importance of proper data flow to support high pixel count displays and the potential impact of disruptive technologies on scientific visualization.

60 Mpx SNL Display Wall Driven by Commodity PC Cluster



**One of three
16 Projector
Arrays (20 Mpx)
Each projector:
1280 x 1024 pixel
TI DLP (DMD)**

Operating at 15 Hz, the system can display 2.7 GBy/sec from a Database.

Database Rendering:

Rendering the 470 million-triangle data to 20 Mpx @ ~80 Mpolys/sec requires ~6 sec/frame.
Each 60 Mpx frame requires 18 sec to render and 180 Mby to store (3 bytes per pixel)

Figure 23-10-20. Sandia National Laboratories 60 Mpx Theater Display.

Virtual experiments drive a need for improved supercomputers to generate results and displays to enable scientists and engineers to analyze the computational results. One example is the simulation of the Richtmyer-Meshkov Instability in which two gases initially separated by a membrane pushed against a wire mesh are subjected to a Mach 1.5 shock, which required the ASCI SST machine with 960 nodes. Another example is the extraction and rendering of a density isosurface from a 73.5M cell AMR mesh model of the non-linear development of unstable shocked interface between two fluids. A third example is a shock physics calculation of re-entry body impact. The big picture for virtual experiments and their display requirements is illustrated in Figure 23-(02,03,04,07,09,11,13).

ASCI is dealing with very large data requirements. Extracting geometry is one effective way to reduce the data before moving or displaying. A recent ASCI computation by LANL on the LLNL White machine involved a 468 million cells mesh (max), 14-25 variables, 364 time dumps, 21 TB of graphics files (652 TB total archived data, including restart files). The ratio of the extracted geometry to the total mesh geometry was nominally 4-5% (per empirical observation). In one virtual experiment, for example, 31.6 million triangles (773 MB) were extracted from a 335 million cell mesh (18.86 GB). The PPM SC99 Gordon Bell Data Set comprised 8 billion cells, 2 variables, 273 time dumps, ~4.3 TB, ~300 GB compressed; for 1 variable these values were reduced to ~8GB, ~550MB compressed; one particular extracted isosurface comprises ~470 M polygons, ~5GB compressed. Thus, even when the data is big, it is often possible to fit one or more full-size data objects on a desktop or laptop local disk

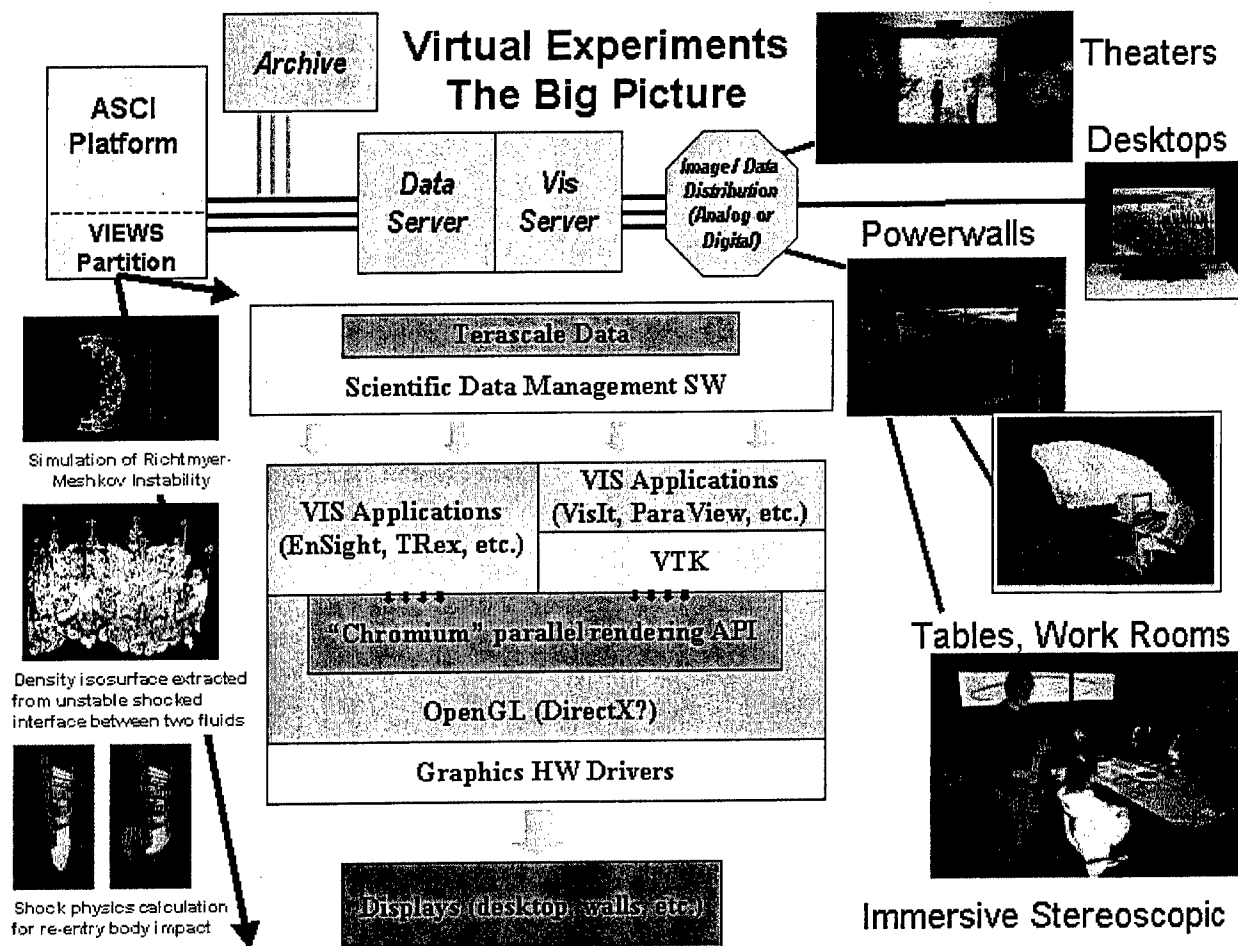


Figure 23-(02,03,04,07,09,11,13). Virtual Experiments and Their Display Challenges. (The center of the diagram is the ASCI developed software stack that allows existing scalar and parallel visualization applications to use cluster rendering without application code modification.)

The virtual experiments involve initial computations on state-of-the-art supercomputing systems. However, rendering polygons from the model computation to pixels for display is based on a strategy of using clusters of PC-graphics cards (e.g. PC clusters). This rendering approach is scalable and leverages the rapid on-going developments driven by the commercial gaming and computing industries. The rendering can occur variously at the supercomputer site or at researchers' labs or offices. Rendering has been demonstrated at 1 Billion polygons/sec in the interactive rendering of a 471 million polygon surface. Software tools include EnSight in combination with Chromium. The ASCI VIEWS program has developed scalable end-to-end solutions for large data set visualization comprising SNL, LLNL, LANL, CEI (Parallel EnSight), Kitware (Parallel VTK), Stanford University (see "The Chromium Project" at sourceforge.net), Princeton University (Scalable Displays), NVIDIA (Linux graphics drivers), RedHat (Chromium and Distributed X Server), and IBM (Bertha displays).

The ASCI display requirements are well beyond the state-of-the-art. Display modalities for ASCI include desktop, theatre, powerwall, and immersive stereoscopic. However, the commercial display market is not developing the high resolution, 10-100 megapixel displays needed by scientists to interact in a meaningful way with the computational results of their virtual experiments. Hence, for the desktop display, the Tri-Labs (SNL, LLNL, LANL) funded IBM \$500K to develop the T221 22-in. 9.2 Mpx AMLCD monitor—the Bertha display (see presentation by Wisnieff)—many years earlier than it would

have been developed if driven only by commercial markets. For the theatre and powerwall displays, SNL developed 16 Mpx and 60 Mpx tiled systems (see Figure 23-10-20). A conference room of the future is being developed for high grade microscope MEMS applications comprising powerwalls and a large 4-8 ft conference table display surface projected from below; contrast ratios of 500:1 and gesture driven interfaces are included.

Display systems are needed for walls, theatres, desktops, and offices. Wall visualizations provide a severe technology challenge: 16-20 Mpx *seamless* projector display system with a full digital audio-visual control system, high resolution image switching (SXGA and higher), automatic projector array adjustments (for alignment, and for correction and calibration of brightness and color); higher contrast ratio projectors (e.g. laser projector?) and graphics cards to render the images. Theatre systems are to be created from several of the wall systems. Desktop and office visualizations require FPDs that can be tiled to create mullion-free electronic table tops and large 40-in. monitors with resolution > 6 Mpx. Funding for ASCI Alliance has been reduced and there are no new Visualization Pathforward plans. Displays with higher resolution and stereo are needed but plans are on hold. Meanwhile, the scalable visualization plans are continuing with a 128 node rendering cluster and an R&D data server being completed during 2002.

The ASCI visualization needs are summarized in Figure 23-23. The highest resolution ASCI display today is a tiled projector array producing 20 Mpx, but with the overhead, maintenance, and visual artifacts (mullions, mis-matched tile alignment, luminance and chromaticity differences and variations within and among tile) associated with current tiling technology. A 64 Mpx display is highly desired by 2004 that will either not have the tiling problems or be constructed from a single 64 megapixel display device.

Visualization Needs of the Advanced Super Computing Initiative (ASCI)

• ASCI needs about 1000 times the performance of today's high end rendering engines in 2004 (unaffordable)

• Today's high end systems are not designed to scale beyond a modest number of pipes

	Today's High-end Technology	2004 Needs
Surface Rendering	~2.5 Million polygons per second per graphics pipe	20 Billion polygons per second (aggregate)
Pixel Fill Rate	~1 Gpixel per raster manager	200 Gpixel (aggregate)
Display Resolution	16 Mpixel (4K x 4K)	64 Mpixel (8K x 8K)

Today's performance figures based on experiences with ASCI-lab applications.

Figure 23-23. ASCI Visualization Needs.

24. ***Professor Sigurd Wagner (Princeton University): "Steel and Plastic Display Science"***

Professor Wagner covered five key enabling technologies for steel and plastic display science created over the past eight years via a collaboration of research groups at Princeton University (Prof. S. Wagner, Prof. J.C. Sturm, Dr. H. Gleskova) and Pennsylvania State University (Profs. T.N. Jackson and S.J. Fonash). These five enabling technologies are (a) flexible and deformable devices; (b) silicon active matrix on steel and plastic; (c) organic circuits on plastic; (d) additive processing; and (e) a "displays anywhere" concept. Professor Wagner gave the roadmap to the realization of steel and plastic displays as follows:

Now (2002): Fabricate in flat geometry on steel or plastic

- Use silicon (poly, nano, amorphous) or organic semiconductors
- Then bend, fold, or shape by plastic deformation

Mid-term: Use additive processes: printing

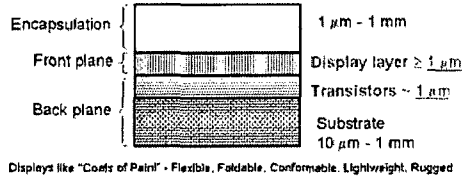
Long-term: Produce display directly on application

Plastic and steel foil substrates for displays have the advantages over glass that they are lightweight, thinner, flexible and deformable, rugged and less prone to breakage, and amenable to future roll-to-roll manufacturing techniques. These product and manufacturing advantages make it highly desirable to develop critical display technologies on such substrates. Of critical importance are technologies for transistors for pixel electronics as well as peripheral control circuitry. In advanced displays a backplane of TFTs, integrated onto a foil substrate, powers a front plane. This front plane incorporates the specific function, such as emissive organic light emitting diodes, or reflective polymer-dispersed or electrophoretic displays. Taken together the backplane and frontplane may be only a few micrometers thick, and therefore can be made to conform to nearly arbitrarily shaped surfaces. We concentrate on TFTs that are capable of matrix switching, CMOS operation, and lend themselves to low-cost manufacture. These TFTs are integrated onto substrate foil of steel or plastic, to make them rugged, flexible, rollable and bendable, and shapeable to non-planar surfaces. Thus the agenda for R&D demonstrations of these TFT backplanes includes (1) silicon and organic semiconductor technologies for TFTs, (2) integration of these TFTs onto foils of steel or plastic, (3) technology for fabrication over large-areas, and (4) the mechanics of flexible and conformally shaped backplanes.

The Penn State and Princeton team has pursued work to enable plastic displays. They have examined developments in amorphous silicon, polycrystalline silicon, and organic semiconductor TFTs on steel and plastic substrates. For silicon TFT materials the challenges are process integration relating to the maximum process temperatures for plastic (for polysilicon), and in the fundamental effects of bending and deformation on TFT performance (for amorphous silicon). Transistors and circuitry on plastic can now be successfully rolled to mm-scale radii or deformed into 3-D shapes. An alternative approach for low temperature TFTs are organic semiconductors, which are deposited on non-crystalline substrates at low temperatures, and shown here to be capable of moderately complex circuits at MHz speeds. These semiconductors are amenable to direct printing techniques, as is demonstrated through the dry-printing of organic dyes into a polymeric organic semiconductor for the full color integration of organic LED's.

Progress made in flexible electronics over the past few years by Princeton and Penn State summarize in Figure 24-02-04-06-12. Efforts to transition enabling technology for flexible backplanes to Sarnoff, Raytheon, E Ink, and Dupont/Honeywell are illustrated in Figure 24-17.

Thin Film Display Structure



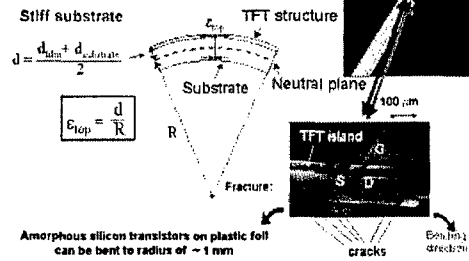
Process Temperatures for Silicon

	Crystalline Silicon	Polycrystalline Silicon	Nanocrystalline Silicon	Amorphous Silicon
Maximum temperature	900°C	600°C (glass) 900°C (steel)	300°C (glass) 150°C (plastic)	300°C (glass) 150°C (plastic)
Maximum mobility (cm ² /Vs)	800	100-200	0.05 - 50	0.5 - 1
CMOS capable	yes	yes	yes	no

- Want CMOS for integrated active matrix + control circuitry
- Plastic limited to low T, laser processing, or circuit transfer

How tightly can we bend a circuit?

- Strain: ϵ = relative change in a dimension
- Stress: $\sigma = Y \cdot \epsilon$ [Pa]



Organic Transistors (pentacene) on Plastic Foil (PEN and PET)

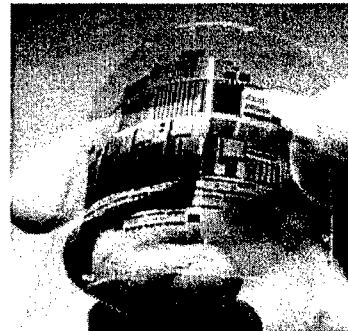
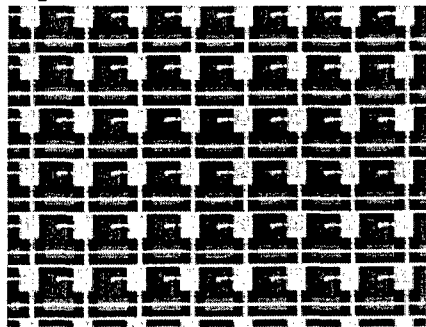


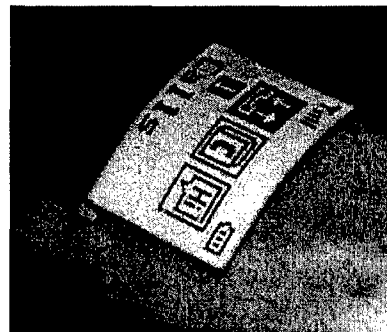
Figure 24-(02,04,06,12). Thin Film Display Structure, Bending, and Processing.

Technology Transfer of TFTs on Steel and Plastic Foil from Penn St & Princeton Flexible Display Enabling Program

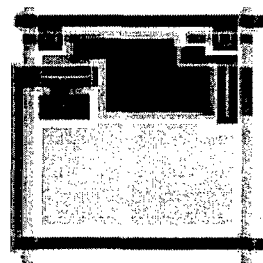
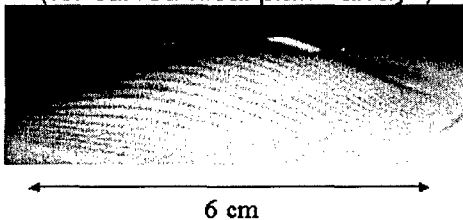
Organic TFT/AMLCD with Sarnoff



a-Si active matrix on stainless steel foil with E Ink for AMEPID



Deformable substrates to Raytheon (for curved focal plane arrays)



a-Si on plastic
AMOLED
with
DuPont,
Honeywell

Figure 24-17. Transfer of Enabling Technology for Flexible Displays to LCD, FPA, EPID, and OLED.

25. Dr. Elizabeth Downing (3DTL): "Approaches to True 3D Displays and Novel Projector Screens"

Dr. Elizabeth Downing of 3D Technology Ltd. (3DTL) in San Jose CA discussed general volumetric display technologies both from a historical perspective and in regards to technologies that are more recent. The talk discussed in detail the attributes of crossed-beam volumetric displays (CBDs), including recent developments along with issues and technical challenges still to be met. Several display opportunities have spun out of the research 3DTL has conducted under DoD support, in advanced optical materials for CBDs and screens for regular 2D projectors.

Dr. Downing asked the rhetorical question of why the US government should care about 3D displays and answered with a quotation by RADM Thomas Bush regarding the Surface Combatant Display Day held 2 April 2002:

"The purpose of Surface Combatant Display Day is to review the Human Systems Integration (HSI) issues and technologies that must be addressed to not only give our warfighters an optimized view of the battlespace, but to quickly and easily facilitate the decisions that will make them owners of that battlespace. There are few decision-makers who can say, "This system gives me exactly what I need." The state-of-the-art in display and related technology evolves daily... The goal of Display Day is to review our shipboard "display battlespace" and consider the art of the possible."

-- RADM Thomas Bush, Deputy PEO for Theatre Surface Combatant

It is envisioned by the Services that true 3D displays may provide improved situational awareness, and the research community realizes that 2D projections of 3D scenes are insufficient for inspection, navigation, and comprehension of some types of multivariate data. Examples include deconfliction of the battlespace, targeting, missile tracking, command and control, data visualization (sensors like sonar, radar, GPS and scientific like medical), air combat mission debrief, and entertainment games. Current 3D display hardware is insufficient to permit even an evaluation of this theory. Government investment is required if true 3D technology acceptable to users is ever to become a reality.

Dr. Downing reviewed three categories of true 3D displays: re-imaging, parallax, and volumetric. Re-imaging displays project an existing 3D object to a new location or depth; these displays produce flat images without true depth. Parallax displays, also known as stereo, are by far the most common and emit directionally varying image information into the viewing zone; these are virtual image displays viewable by just one person. Parallax displays include those based on lenticular arrays, stereo glasses, and holographic. Holographic displays would be ideal except for the fact that the data bandwidth of high quality holograms is beyond current synthesis and electronic device technology (need 1550 line pairs per mm). Volumetric displays address and illuminate volume elements (voxels) within a spatial volume; these displays are direct-view as the image elements are actually located at the position at which the eye focuses, enabling multi-person viewing and comfortable viewing for extended periods. There are several types of volumetric display including rotating arrays of LEDs, LCD stacks, LC shutter stack addressed with a MEMS device, and laser scanning. The Swept surface laser scanning involves voxels written via a careful synchronization of the motion of a reflecting surface with the scanning and modulation of a visible laser. Crossed-beam laser scanning involves co-scanning two infrared lasers in a solid matrix with 3D continuous lines of non-coherent visible fluorescent resulting from gated two-frequency upconversion; these are known as crossed-beam volumetric displays (CBDs). Volumetric displays provide real depth cues with eye convergence and focus at the same point. Other true 3D approaches create headaches, nausea and discomfort because they present the eye with a conflict between accommodation (focus) and convergence distances, and because they require the wearing of headgear or

glasses. Volumetric displays permit 360° walk around viewing by multiple viewers simultaneously; they can be interactive and dynamic, and multi-chromatic with grayscale. The CBD volumetric displays emit incoherent visible radiation (no eye-fry hazards). Optical addressing information in a volumetric display eliminates the need to embed wires, electrodes and transistors in the volumetric imaging medium (volumetric screen) reducing manufacturing cost. However, lasers and the electronics to scan and modulate them are required, raising the cost significantly.

Technical obstacles confronted efforts to develop and commercialize CBDs. Initial image chamber materials were low luminance, heavy, and hard to manufacture. Commercial laser diodes had limited wavelengths and powers but high cost. Computer bandwidth is not an issue because the optical materials do not support high speed scanning; applications are restricted to those with small datasets. The people most desperate for real volumetric visualization generally have small data sets (10,000 voxels). Funding from the DARPA Electro-Active Polymer (EAP) program had the goal of inventing upconverting plastic materials to permit CBD image chambers that are bigger (up to 24 in.), brighter, cheaper, lighter, and addressable in color. The challenge would then be transition via fabrication of device hardware for user evaluation. Programmatic issues that confront the effort include clever systems engineering to push the technology just above that “good enough” threshold of price/performance. Also, it is a mistake to develop critical components of a system level technology isolation from the system hardware; component developments are tightly coupled in the creative conscience of developers. A historical account of CRT development in terms of luminance (brightness) is compared with that for CBD in Figure 25-18. The luminance of CBDs has improved as much from 1997 to 2001 (4 years) as did CRTs from 1952-1972 (20 years). Also, the invention of color television took 22 years (1950-1972). Thus, it is not unexpected that systems based on improved CBD materials may take a few more years. Once CBDs become available they might be tiled into a 2x4 array to create a large 3D sandtable.

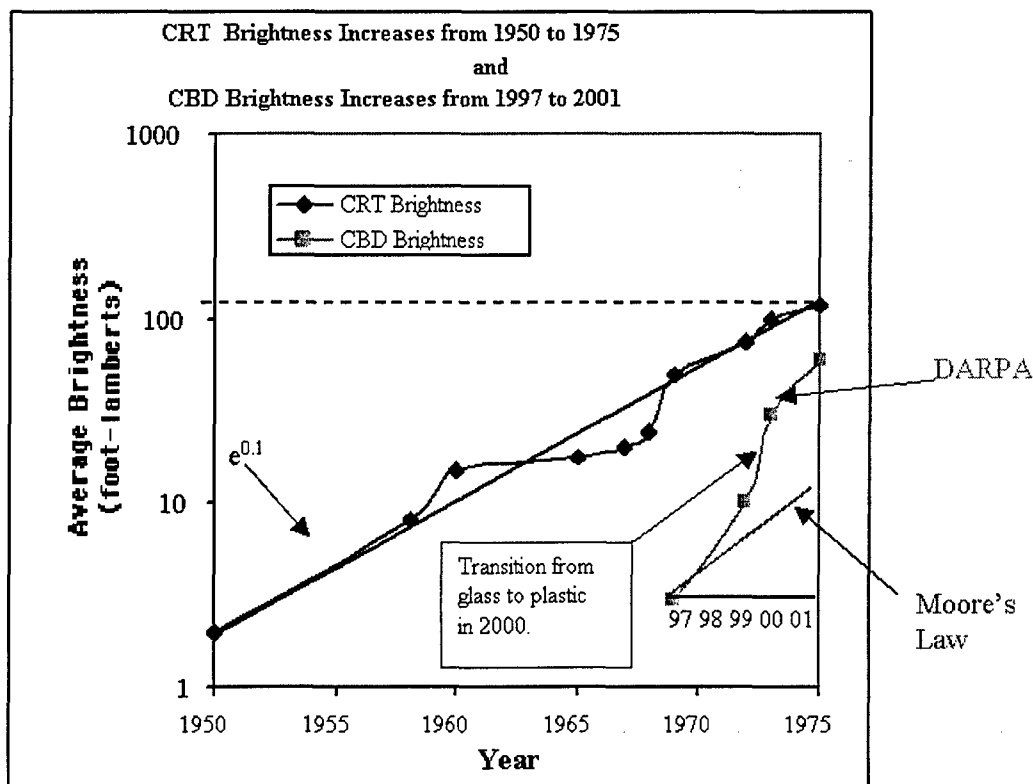


Figure 25-18. History of Luminance for CRT vs. CBD (Cross Beam Volumetric 3D Display).

Transition is a programmatic black hole for DoD displays research—funding is not available. For example, the CBD technology is stuck in the gulf between the high-risk DARPA funded materials R&D (exploratory research) and the low-risk engineering development that the Navy is willing fund to help specify hardware and human factors requirements, and to test and evaluate the CBD system technology *after* it is delivered. There is no DoD program funding for the advanced development to build CBD prototypes. Development work to transition of a technology can cost far more than the research. Initial government funding is needed to pave the way for commercial sales of a new American display industry. DoD should address the programmatic funding gap of transition funding.

Another new concept presented by Dr. Downing is a transparent emissive display (TED) formed by coating a windshield with EAPs to form a screen that is addressed with a laser. Windshield curvature would have little effect on TED performance. The EAP material might even become the basis of a "Spray Display" dispersed to any surface via an aerosol can and then scanned with a small laser scanning device. This concept shows the unexpected directions research can take to create new applications options; funding agencies should always permit this flexibility to optimize the technology return on investment.

Dr. Downing also showed a novel, "out of the box," application of inorganic LED displays in clothing: lighting designed and embedded into a wedding gown.

26. Dr. James Larimer (NASA Ames): "Bandwidth & Power Requirements to Reach the Future"

Dr. Larimer began by pointing out that in the 1700's visual information was conveyed in small hard copy packages (books and newspapers) and posed the question of whether the quality visual information technology has improved since. He pointed out that 6 point print 300 years ago was very legible but that current day electronic displays could not convey this level of detail. The pixels per inch (ppi) implicit in 6 point text is about 300 ppi. Dr. Larimer provided pictorial examples of how absolutely illegible 6 point textual material is when rendered leading edge electronic display technology circa 1985 (50 ppi), 1992 (75 ppi), and 2002 (200 ppi); and typical 2002 technology is just 100 ppi, not 200. Only when electronic displays with spatial pixel resolution to 200 ppi or slightly more become common will we approach the text rendering quality of print in the year 1700. Dr. Larimer pointed out en route to better definition electronic displays we had to replace the Braun Tube, or CRT, the 100+ year old workhorse of electronic displays, with the active matrix flat panel display (FPD). The active matrix is used as a pixel level memory today's FPDs and has enabled higher dot densities and flat screens.

Several reasons were given to make the case that high-resolution is worthwhile, including better text rendering and smaller fonts, larger spreadsheets, precise graphics (for mechanical drawings, circuit diagrams, chip layouts), virtual windows for surveillance (improved detection, recognition, identification), tele-presence, tele-operations, tele-communications, veridical imagery (perfect replica of images and photos, ideal dynamic visual media), and higher information density per unit area.

Dr. Larimer posited that the field of view (FOV) is critical for several warfighter tasks. Understanding depends on context; a visual example was provided to illustrate how an object or cropped scene may look different in the larger context. Situational awareness (SA) is enabled by larger FOVs; two urban satellite images of Manhattan with different FOVs were used to illustrate the conclusion: FOV = SA.

Dr. Larimer then posited that higher resolution is also critical for several warfighter tasks. Object detection and recognition requires higher resolution. Two satellite images with the same FOV, one with "low" resolution, one with "high" resolution, were used to make the point that critical features can be

detected and recognized when more information is provided than currently fielded displays can render. Detection leads to recognition when higher resolution is available and less magnification, panning, zooming is required; resolution leads to identification when information available on the computer disk is presented as a single image.

Getting electronic displays to be equivalent to print required more than high pixel density—it required bandwidth and power. For a 4 x 7 in. format personal digital assistants (PDAs) with paperback resolution, current practice mass production displays require bandwidth and power of 5.6 Mbps and > 0.5W; and state of the art PDAs require 1.6 Gbps and too many watts. For an 18.8 x 11.7 in. display presenting two pages side by side, current commercial practice requires 1.6 Gbps and ~70 W; and state of the art, 13.2 Gbps and ~150 W. The power is computed as $P = 0.5 \text{ cV}^2 f$. Houston, we've got a big source and a big sink: a big problem! High bandwidth multimedia sources (cameras, broadcast, cable, digital media, image rendering engines) need to be presented to users. Dr. Larimer then presented his analysis of "matching the eye—how much bandwidth is required," as follows.

Spatial resolution is measured in units of degrees of visual angle, because these units define fixed extents on the retina. If the image size of two objects at the retina is the same, they are sampled by the same number of photoreceptors; more detail will be visible in the near object. The eye spatially samples the retinal image; photoreceptors distributions are not uniform and provide inhomogeneous sampling. Foveal packing densities vary among individuals; some are "eagle eyed." A photoreceptor density map shows distinct regions including the nasal retina 5° parafovea, the peripheral retina 22° temporal to fixation, and the peripheral retina 60° temporal to fixation. In first region is dominated by cones with few rods; the second two regions have higher densities of rods.¹⁹ For the average observer, the region of best spatial vision, the fovea, takes ~120 samples per degree; individuals can differ in a range from 90 to 190 samples per degree. (Reference: Curcio, Sloan, Kalina, Hendrickson, 1990).

Temporal resolution depends on object luminance and contrast. The eye temporally samples with a sampling period that depends on the brightness level. Bright high contrast temporal variation is required to see flicker above 80 Hz. A plot of contrast sensitivity versus temporal frequency was presented to show that temporal sampling rate ranges from less than 2 Hz for dim objects to over 60 Hz for bright objects. (Reference: de Lange, 1958)

Luminance often varies dramatically within an image. Natural scenes have an enormous dynamic range—easily 10^5 to 10^6 on a bright sunny day. Human eyes have a local gain control to enable detail in dim and bright areas of the FOV to be easily seen as the eye scans the scene. This effect was demonstrated with three images of a room with a window looking out on a bright day: camera exposure for interior view (window views are blobs of light); camera exposure for exterior view (view through windows clear, room is a mass of black), and an image with local gain control to show what the eye sees. Local gain control in an image system can save bandwidth.

Retinal images are processed by a neural network. A putative simplistic equivalent circuit model of the visual pathway within the eye was presented showing images on the retina, cones, and a three-octave differential amplifier network (high, mid, low spatial frequency octaves) creating signals that pass on to the brain to generate perceptions. Neurons have a dynamic range of ~300:1 with less than 1% signal to noise ratio (SNR), which implies 10 bits with log spacing.

¹⁹ Signals generated in the cones lead to the perception of high-resolution "images" in the brain. The peripheral retina responds faster than the central retina, and is more sensitive to low light levels albeit with lower resolution; these differential sensitivities of the central and peripheral retinal areas contribute to the perception of motion.

From the foregoing an upper bound estimate of the eyeball's channel capacity is 11.5 megabit/sec/deg². This estimate is based on spatial sampling of 120 cone detectors per degree at the retinal locus of best spatial vision (and less elsewhere) for the average person, temporal sampling of 80 Hz for very bright and high contrast images, and tonescape, or dynamic range, of 10 bits for neurons. An upper bound conservative estimate of the total eyeball channel capacity is 1.2 gigabit/sec based upon 1.5 million neurons in the optic nerve.

The channel capacity of selected devices is summarized in Table 26-1. From the data in this table it is apparent that high-resolution displays make enormous bandwidth demands on the image communications infrastructure. Just one IBM T221 display requires 6.64 Gbps to run at 30 Hz; that is, 67 times the entire bandwidth of a T100 ethernet is required for one display device. High-resolution displays are available today in a ranges of sizes for a wide variety of applications; features include RF connectivity to a network and variable resolution clients. Examples include large area desktops (22 in. diagonal, 16:10 aspect, IBM T221, 3840 x 2400, 204 dpi pixel density) and small handheld information appliances (Palm Devices, Pocket PCs and Blackberrys in various aspect ratios with 105-140 dpi pixel density).

The question is: how to we get the necessary network bandwidth (wired and RF) with eye-matched devices? The answer is that just as active matrix enabled eye-matched display devices, it can also enable a smart system. Current systems behave like "write often" memory. There is room in the display matrix and on its edges for more devices (microelectronics) that combine image processing with image reconstruction. Functionality that can reduce bandwidth and power includes local automatic gain sensing (AGS), self-refreshing memory, random addressing, asynchronous addressing, implicit pixel shifts to the right and left and up and down, implicit anamorphic scaling, and multi-resolution reconstruction. A new architecture based on asynchronous random addressing and signal processing similar to MPEG embedded in the reconstruction device will solve this problem. A lot of work remains to be done to deliver the dream of eye-matched imagery that is untethered, portable, and available on demand.

Dr. Larimer concluded by stating that a new era is dawning. We must move beyond the Braun Tube Architecture of serial image communications required to service the CRT device and replace this architecture with a smart architecture that can give us the untethered thin client required by the information age.

Table 26-1. Channel Capacity for Selected Devices Viewed at 500 mm.

Device Type	Channel Capacity	Comment
1 sq. deg. Sony Cliè 16 bit color @ 10 Hz	0.37 Mb/sec/deg ²	
1 sq. deg. IBM T221 @ 30 Hz	3.33 Mb/sec/deg ²	
1 sq. deg. IBM T221 @ 80 Hz	8.88 Mb/sec/deg ²	
1 sq. deg. <u>Human Vision</u>	11.5 Mb/sec/deg ²	
T100 Ethernet (entire channel)	0.100 Gb/sec	
Palm Device (2.25 x 2.25 in., 204 dpi, 30 Hz, 24 b)	0.152 Gb/sec	Approx. "Eye Matched"
<u>Human Vision</u> (whole eye)	1.2 Gb/sec	For gaze in fixed direction
IBM T221 @ 30 Hz (entire display)	6.64 Gb/sec	
IBM T221 @ 80 Hz	17.7 Gb/sec	Approx. "Eye Matched"

27. **Dr. H. Lee Task (Task Consulting - Sytronics):**
"Human Factors Issues in AF Displays; Including Night Vision"

Dr. Task began by agreeing with the human vision analysis presented by Dr. Larimer. His presentation covered display usage in the Air Force, display parameters and related vision parameters, and specific human factors issues with respect to electronic displays. A model was presented comprising input, display, vision, and processing (brain). Input comprises power, signal, and noise to a display characterized by resolution, luminance, spectrum, and size. The image from the display is viewed by a human eye defined by parameters including visual acuity, brightness, color, and field of view. The processing of the output of the eye by the brain leads to perception, which is affected by knowledge, training, experience, and fatigue. Display usage in the Air Force includes aircraft applications (panel displays, HMDs, HUD, NVDs), simulators (LARGE displays, HMDs, HUDs), command/control centers (LARGE displays), and miscellaneous applications (mostly COTS). Display parameters, their visual effects, and representative values were compared as shown in Table 27-1.

Visual acuity was illustrated with a log-log graph of visual angle in minutes vs. brightness in mL for various contrasts in the range from 2 to 50 %, all based on a 50% probability of seeing (source: Cobb and Moss, "The four variables of the visual threshold," Journal of the Franklin Institute, 1928). One arc minute visual acuity corresponds to 50% contrast at 20 mL brightness, but to 20% contrast at 100 mL. The modulation transfer function (MTF) of a display and contrast sensitivity function (CSF) of the human visual system were next described; both are functions of spatial frequency in cycles per degree with the MTF monotonically decreasing; and the CSF, increasing; the spatial frequency at which the MTF drops to intersect the rising CSF is defined as the limiting resolution. The field of view (FOV) relationship with resolution was characterized by stating that N pixels in a small field of view is high resolution relative to the same N pixels in a large field of view. This effect was illustrated with a figure showing the night vision goggle (NVG) MTF for 20° and 40° FOVs; the MTF curve for 20° meets the rising CTF curve at about 17 cycles/degree; the MTF for 40°, at about 12.5 cycles/degree. The main point of this illustration is that doubling the linear resolution of a display does not necessarily result in doubling the limiting resolution (the equivalent visual acuity at the eye).

Environmental visual performance factors were described using a pilot's eye of the world. Illumination levels vary for various portions of terrain and the atmosphere and change as the pilot flies. Target parameters include contrast, reflectance, size, shape, color, and pattern; background parameters include reflectance, distribution, and color. The altitude, distance and atmospheric effects affect the light that reaches the aircraft from ground or air targets in complex ways. Once light arrives at the aircraft, the windscreen, HUD combiner, and helmet visor each separately affects the light that actually gets to the pilot's eyes; parameters used to characterize each of these transparencies include transmissivity, haze, reflections, distortion, and defects. Then the visual acuity factors discussed above enter. Other visual performance factors for pilots include speed, time, g-loading, workload, stress, experience, training, and motion.

The AN/AVS-9 pilot helmet-mounted night vision goggle was shown via a photograph of a subject wearing the helmet ensemble. The key NVG component is the image intensifier tube (IIT), which has a diameter of about the size of a quarter. These systems permit vision using near infrared (NIR) energy even when there is insufficient visible light to see. The NIR scene light is collected by an objective lens and focused onto a photocathode where NIR photons are converted to electrons; the electrons are spatially sampled by the thousands of entrance channels to a microchannel plate; high voltage across the microchannel plate amplifies the electron currents within each of the 7 million microchannels and moves them to impact a green phosphor screen to produce thousands of green dots which are focused to the eye of the viewer by an eyepiece lens. Thus, an invisible NIR scene is converted to a green image at relatively high spatial resolution equivalent to over 5 Mpx within the NVG FOV,

which is typically about 40° in currently fielded systems (corresponding to about 20/25 visual acuity). The spectral sensitivity of unaided vision and NVG-assisted vision were illustrated by plots of the relative sensitivity as a function of wavelength of (a) vision of the unaided eye; (b) NVG A; and (c) NVG B. The two NVG standards have low sensitivity in the visible region from about 440 to 650 nm, but high sensitivity in the range 600-900 nm. There are actually two NVG standards, A and B. The NVG B standard is typical of pilots as it has a cutoff at about 630, which permits instrument panel displays to have some red in them without causing the goggle to "bloom." The NVG A standard is typical of warfighters flying with aircraft cockpits that do not have color displays (no need for red). NVG compatibility was discussed using a plot of relative luminance versus wavelength for vision, incandescent light, and NVG A. Most of the energy of incandescent light is in NIR rather than in the visible.

Night vision goggles involve special human factors (HF) considerations. Compatible instrument panel displays are required that have a mode that minimize their output in the NVG sensitive NIR and red part of the spectrum while minimizing color distortion (especially red), maintain daylight luminance, and prevent luminance imbalance with respect to the NVG output. Some NVGs have an added display capable of portraying symbology overlaying the NVG image. This so-called NVG-HUD has a miniature display added (internally or externally) to enable symbology (and possibly other imagery) to be overlaid on the image coming from the image intensifier tube. This NVG miniature display needs to have a high transmission / high blocking (on/off) shutter for image insertion, reasonably high resolution matching the 20/25 equivalent resolution of the NVG (current day micro-FPD devices are less than 1 Mpx), and good light control range and color.

Table 27-1. Display Human Factors Parameters.

Display Parameter	Vision Effect	Vision Limit or Range
Resolution	Visual Acuity	1 arc min (+/-)
Luminance	Brightness	0.01 - 10,000 fL
MTF	Sharpness/contrast	30 cy/deg (1.72 cy/mrad)
Spectrum	Color (hue, saturation)	400-700 nm; 7-9 colors
Surface Reflectivity	Contrast (glare)	0.05 - 1.0 (modulation)
Size (format)	Field of view (fixed head position)	Approximately 200 x 130°
Refresh Rate	Flicker perception	> 70 Hz
Update Rate	Motion perception	
Active/Total Area	Masking	
Luminance Direction	Viewing angle	
Distortion	Motion perception	0.3 mrad/deg ?
On/Off ratio	Contrast perception	50:1 500:1
Jitter	Movement perception	<< 1 arc min
Defects	Distraction, error, masking	<< 1 arc min
NVG Compatibility	Color, brightness, contrast, etc.	

*Note: New parameters may be required as new display technologies manifest new visual impact effects. Example: image break-up during eye movements due to lack of display persistence in old LED calculator displays.

Recently, a wide FOV NVG has transitioned from advanced development at AFRL to three engineering development programs, one in each service. This panoramic night vision goggle (PNVG) has a field of view of about $95 \times 38^\circ$ based on the use of an array of four advanced, 16mm"gen-4 IITs. This wide FOV comprises three overlapping sub-fields of view: two outboard channels viewable to either the left or right eye, and one center $38 \times 38^\circ$ channel providing binocular vision. A new advanced development program is underway at AFRL to improve the PNVG by including internal miniature displays (microAMOLEDs) for symbol overlay and image insertion, as shown in Figure 27-20.

Dr. Task concluded by discussing the two types of night vision devices: (1) night vision goggles (NVGs) which combine the sensor and display into a single device worn on the head (that do not require a head tracker); and (2) sensors mounted on the aircraft that produce a video-rate image that is transmitted to an instrument panel display or to an HMD equipped with a head tracker and miniature display image source. Special human factors issues for the miniature display HMD image source for pilots include high daytime luminance, high resolution for wide FOV, good luminance control for night use, potential for color, light weight, low power, possible "night vision" use. Special human factors issues for miniature displays as the HMD image source for maintenance applications are fewer but include high resolution, high luminance, color, light weight, and low power. Hardware samples of NVGs and helmet visors were demonstrated.

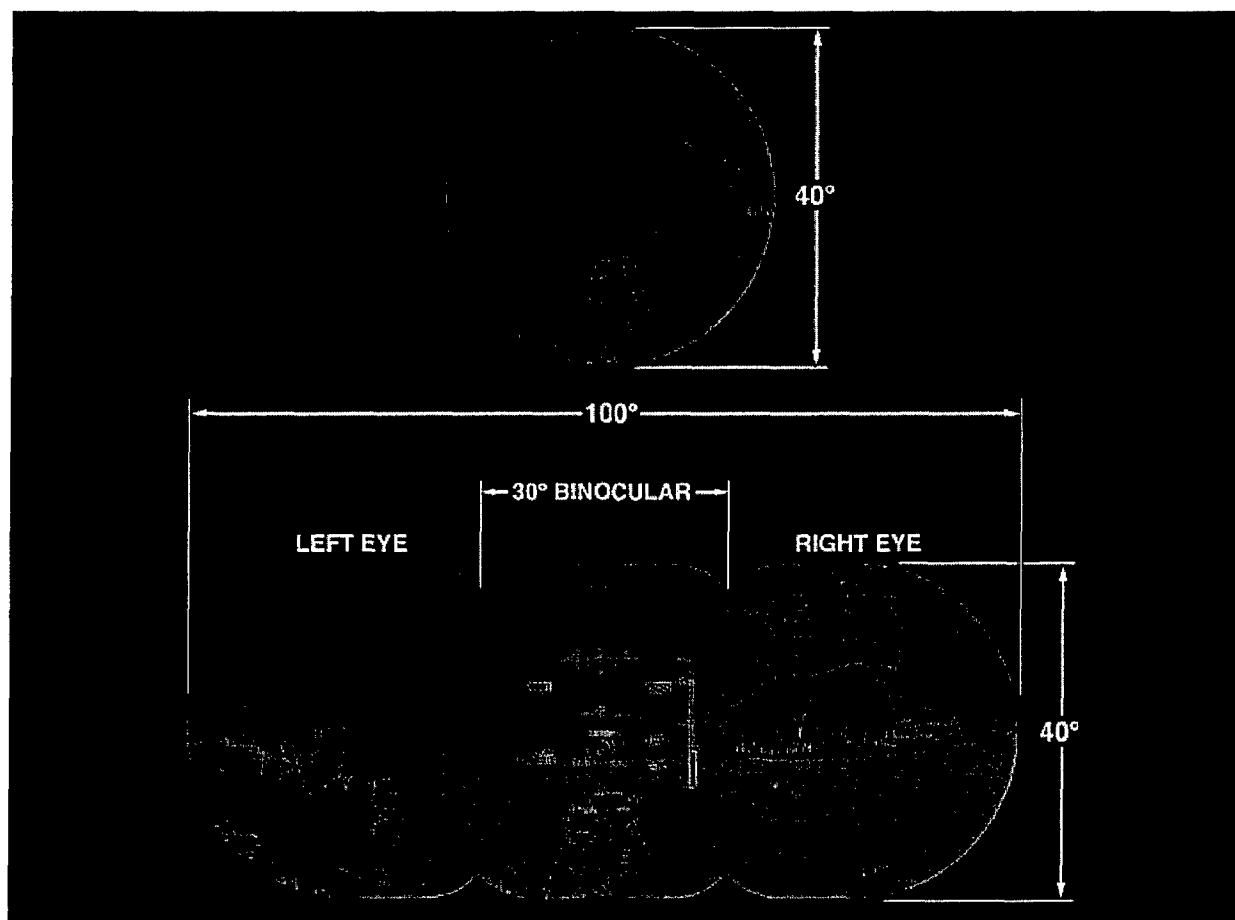


Figure 27-20. Panoramic Night Vision Goggle (PNVG) Improved With Embedded Miniature Displays.

28. ***Dr. Webster E. Howard (eMagin Corp.): "Display Innovations – From Research to Products"***
(Edited by Dr. Gary Jones, CEO of eMagin)

Dr. Howard based this talk upon his 30 years as a display researcher working on a wide variety of technologies, at IBM, ATT/Lucent, and eMagin. The talk addressed the management processes by which display technologies get from the research stage to products and discusses a set of examples of research projects, some of which became successful products and some of which were abandoned.

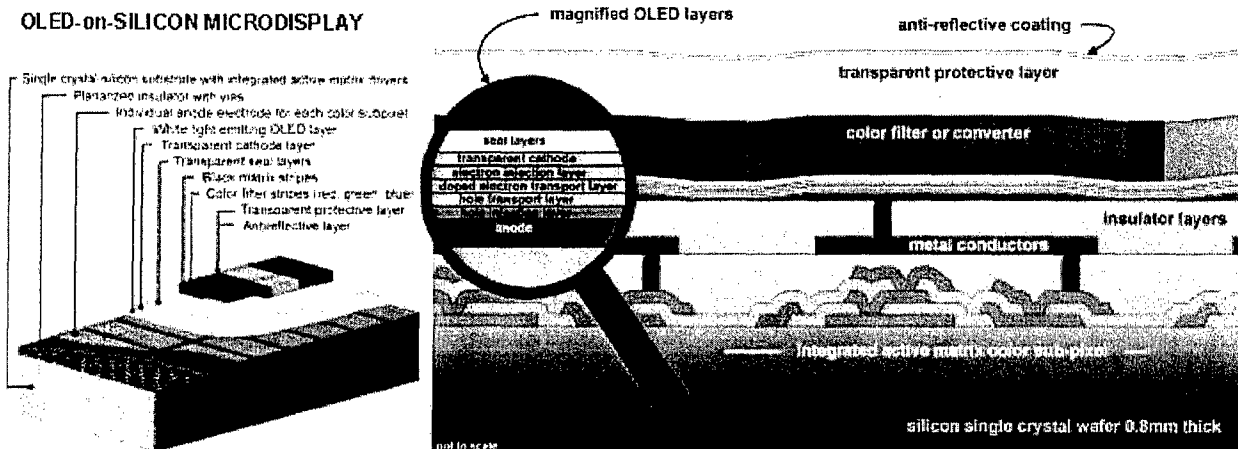
Plasma panels in IBM are an example of a technology which originated outside the company, and a research program was set up to improve and perfect it in order to make it a reliable product. It is also an example of underestimating a moving target, as the CRT displays which were to be replaced became much better and cheaper than expected, leaving the early plasma products noncompetitive. Other display technologies worked on in IBM Research included electrochromics, thin film electroluminescence, passive matrix liquid crystal displays, and multibeam CRTs. Each of these was abandoned for good reason, and it can be argued that some should not have been started.

Thin film transistor/liquid crystal displays, now the most successful flat panel technology ever, persevered within IBM over strong internal resistance. Fortunately, a disciplined, fair process ensured that decisions at least would be well considered. While the decision process used was slow (>18 mos), it had a lot to recommend it in terms of risk reduction, and in the case of TFT/LCDs it resulted in commercial success. Even with a good process, however, it is essential to have strong advocates, or champions; otherwise a decision may never be made.

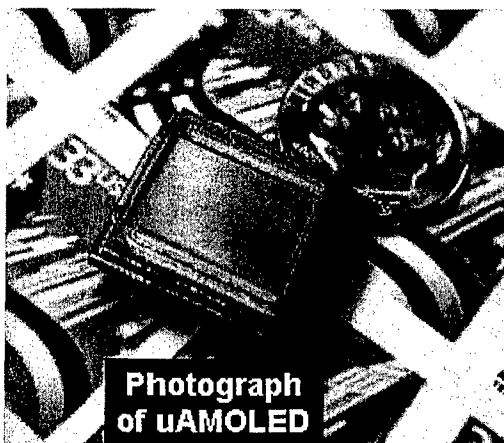
The same TFT LCD technology, at ATT/Lucent, was subjected to a quite different management process, and the outcome ultimately was abandonment of the technology, after an expenditure of about \$40M, including about \$15M of DARPA funds. While in one sense the project was struck by an asteroid, the breakup of ATT, the handwriting had been on the wall for its demise as a consequence of the corporate management structure and measurement system. The technical team had done a great job, but there was not enough product division pull, and no way to fund manufacturing without wiping out a lot of bonuses.

The development of OLED microdisplays based upon silicon integration at eMagin Corporation is an example which brings out the differences in large company and small company environments for display research. A small company, necessarily accepting more risk, can move more rapidly to develop a new technology, but on the other side the resources of a large company can facilitate the transition to high volume manufacturing once the technology has been developed. The ideal is probably a partnership between large and small companies. Dr. Howard described the eMagin miniature active matrix OLED (uAMOLED) based on Kodak OLED materials that was developed from 1997 to 2002 under \$22M AFRL and 0.5M U.S. Army CECOM funding as illustrated in Figure 28-(20-21-22-23). Each RGB sub pixel originally had a two transistor design pioneered in part via DARPA funding at Lehigh University. Currently, eMagin has a six transistor at each RGB pixel cell design; this unique eMagin design stores the image under each subpixel to minimize power, flicker, and external memory requirements. eMagin uses single crystal silicon for its backplane, which makes it possible to compact many transistors under each cell and to operate the cells at high speed (full motion video). The rapid development of uAMOLED display products was only possible because of eMagin management was able to make decisions more quickly and to accept far higher risk than larger company structure would permit. The SVGA uAMOLED illustrated is being evaluated for use in HMD programs in the Air Force (IPNVG, SH21) and Army (LW).

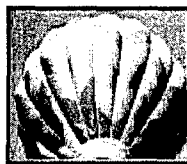
OLED-on-SILICON MICRODISPLAY



eMagin Micro-AMOLED



Photograph
of uAMOLED



Photograph
of operating
uAMOLED

- SVGA+ format
(852 x 600 color pixels)
- 0.62 in. diagonal
- Analog input
- > 100 cd/m²
- 256 gray levels
(16 million colors)

Figure 28-(20-21-22-23). eMagin SVGA+ Miniature-AMOLED on Silicon.

Dr. Howard concluded by noting that there is currently a trend for technologies like flat panels to be taken over by Chinese factories, or joint ventures with manufacturing in China. This trend could put DoD back in the position it was in the early 1990s, with an uncooperative Japan as the only supplier of flat panels. Right now, Korea and Taiwan are dominant, but this may not last. Once China would have taken over FPDs from Korea and Taiwan it may prove to be as uncooperative as was Japan ten years ago.

There is a trend for technologies like flat panel displays (FPDs) to be taken over by Chinese factories, or joint ventures with manufacturing in China. This trend could put DoD back in the position it was in the early 1990s, with an uncooperative Japan as the only supplier of flat panels.

-- Dr. Webster E. Howard

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FINDINGS

AGED STAR ON DISPLAYS (APPROVED BY AGEDC ON 26 NOV 02)

Findings by AGED are based on the presentations by the speakers and classified here into four groups: Access, Planning, Investment & Payoff, and Transition.

Access

Finding 1: Heavy reliance on COTS display products and components bears a risk to DoD. Risks include the possibilities that adversaries may use COTS more effectively than DoD and that DoD inaction may lead to loss of technology advantage on battlefield (technology surprise) by foes strongly motivated to innovate with consumer technology. An additional risk is geographical: virtually all COTS displays are manufactured in Asia. An additional risk is the trend for electronics manufacturing, including displays, to move from Korea, Japan, and Taiwan to China.

Finding 2: Avionics displays typically require custom designs and manufacturing runs in mass production civil-product driven fabrication facilities. Custom designs continue to be necessary to meet many of the specific size, environmental, and advanced performance requirements for applications like fighter cockpits, ground air operations controllers, and specialty applications in ground combat vehicles.

Finding 3: There is concern in Congress and among small industry and academia over the lack of thin-film transistor (TFT) foundries in the US. Visibility into manufacturing issues is inhibited by time, distance, et cetera, and speed of device research is slowed. The US needs some manufacturing expertise to leapfrog to next generation display technology. DoD must assess and conditionally promote on-shore sources for TFT fab. for AMLCD, AMOLED, and other advanced display technologies requiring an active matrix backplane. Infrastructure will disappear if no manufacture of advanced displays is undertaken in the US. Also, such current US-based manufacturing as exists (e.g. MEMS DMD, MEMS GLV, true 3D, TFEL, passive matrix LCD, other) should be encouraged and retained.

Planning

Finding 4: Congress has consistently appropriated funds for DoD electronic displays RDT&E at twice the level of the President's Budget Request (PBR). The current state of affairs is that DoD does not plan properly, but must play catch-up and rely on Congressional adds.

Finding 5: DoD does not motivate the industry sufficiently by facilitating participation in maintaining an awareness of the display needs and experiences of operational warfighters.

Finding 6: Civil display industry is growing rapidly. The 2001-06 compound annual growth rate projected is 3% for CRT but 21% for FPD. FPD is becoming the dominant technology, projected to surpass CRT in sales in 2002. FPD (mostly AMLCD) doubled from \$11B in 1998 to \$22B in 2001; projected \$45B by 2005. All other technologies (than CRT and AMLCD) are presently supported only by niche markets. Plasma may wane for large thin, wall-TV applications as AMLCDs grow to 53-in. in 2003. Projection technologies are substantial and growing (mostly small CRT, mini-AMLCD, DMD). OLED is beginning to appear in segmented character product offerings; video products have been prototyped. The total number of displays installed across all DoD weapons systems is less than 450,000 compared to tens of millions of units manufactured yearly for civil products.

Finding 7: Low weight, volume, and power are demanded by many civil applications. Mobile flat panel displays are one of the fastest growing display markets, estimated to be \$14B by 2002. Needs for pervasively available information places new demands on mobile displays, requiring new display technology with higher information content, ease of readability in dynamic environments, and low power consumption, all while not compromising device portability.

Investment and Payoff

Finding 8: Space, weight, power, and performance for displays are more critical to DoD than to the civil market (esp. in combat air/land craft, special tactics mobile/portable gear). Low total display product weight, including power source (spare batteries, fuel cells, other), is a pervasive, severe, demanding requirement in all mobile applications, but is significantly more severe for DoD special forces and other dismounted warriors than for gamers and business roadwarriors. Cost is significantly less important to military than civil markets. Manufacturability is critical to both the civil and military markets, but must often be invested in for displays by the military because its needs precede civil markets by several years.

Finding 9: Display systems have become a bottleneck for the information age. Current display technology does not even remotely tap the potential of the natural vision system. Image architecture from capture to reconstruction is changing, and there is a need for a new end-to-end architecture—sensor/computer to C2 display to decision to shooter display—tailored by level.

Finding 10: Bandwidth requirements are pushing computational functions into the displays. Active matrix displays introduced microelectronics into each pixel of the display screen. A present trend is to transfer more computer functions into each pixel and display device. Candidate functions for transfer into the display include memory, radio chips, communications and compression/decompression circuits in the near/mid-term, and complete processors within each pixel in the far-term. Rapidly growing video bandwidth is a problem that should be addressed in the display *per se*.

Finding 11: The primary human input device is vision; it totally dominates all other modes of gathering information. The full capability of information systems will not be realized without improvements in the human system interface. Everything needed to create the image from an electronic representation comprises the display. The nature of human vision and the way it interacts with displayed images impacts display requirements on an application specific basis.

Finding 12: In the last two years DoD identified, but did not fully fund, efforts to create display technology critical to defense. The March 2001 DoD report to Congress identified needed new thrusts to create 25 megapixel, true 3D, and novel display devices and systems. Also, daunting challenges remain in the development of flexible displays.

Finding 13: The US leads in display research but with the current lack of investment the US research lead will vanish. Flat panel displays and other advanced display technologies were created in the US, but virtually all production is in Asia. The US and DoD lever has been its intellectual property position. Because DoD has pulled back its investment level in display S&T by two-thirds, US industry has less incentive to invest in the US. Research has begun to move to Asia as well.

Finding 14: Government/industry/academia partnership in technology spurs development. DoD S&T agencies must lead search for new display technologies and seed promising avenues. Consumer applications are not likely to support development of, for example, the ultra-high resolution devices that would fit military simulation needs. Such S&T investments in displays have enabled a revolution in military affairs (RMA) in the past and are poised to so repeatedly during the next decades. Revolutionary

progress in displays depends on new materials; the only "breakthroughs" occur at the materials level with government research support.

Finding 15: Investment of \$100M per year by DoD for display research is not unreasonable to influence the high end research (1.5-5B/yr) performed by the \$150B per year display industry, including \$50B for display components. Total displays S&T investment across DoD totaled over \$1.2B from 1989 through 2001.

Finding 16: Display research is critical to the U.S. military. Opportunities exist to make a significant difference in applications ranging from special operations forces to combat pilots to dismounted combatants to headquarters commanders. These investment opportunities not covered by what happens abroad to address service consumer market needs.

Transition

Finding 17: DARPA has ended its 13-year (FY89-01) dominance of defense display S&T. Total displays funding via DARPA (PBR and, especially, Congressional) during FY89-FY01 totaled \$912M. DARPA's position is that the services must undertake technology maturation, transition, and insertion efforts of its HDS technologies into platforms.^{20,21}

Finding 18: Industry recommends that DoD fund efforts to adapt rapidly changing civil display industry offerings to defense needs where applicable. Continual defense research on ruggedization and integration is needed to enable the effective leveraging of displays designed for dynamic, consumer-market driven product cycles. At present many defense applications are forced to use COTS technology even when it does not meet the performance specification. System optimization is limited by the independently optimized COTS technology cycles (new commercial designs every 18 months compared to DoD system engineering over years and sustainment over decades).

²⁰ For example, all three services have transitioned avionics-grade AMLCDs to most of their aircraft cockpits. Also, the Air Force and Navy have transitioned the DMD technology to airborne and shipboard applications, and the Army has transitioned TFEL to ground combat vehicles. Significant further service investments will be needed to pick up on the \$50M-\$75M per year that DARPA had been spending on other aspects of display research.

²¹ There are many other opportunities where defense advantage is foreseen in which the services could invest to transition the materials and nascent device display technologies from the DARPA High Definition Systems (HDS) program. One such area is flexible rollable displays, an area in which DARPA invested over \$50M, mainly in FY00-01, to initiate creation of a technology base. The Army has initiated a flexible display initiative of \$54 over the six year period FY04-FY09 to enable the development of emissive and reflective flat panel displays with flexible substrates. These displays based on flexible substrates offer the opportunity for rugged, rollable, characteristics to meet the demands of the objective force warrior (OFW). This program will address the critical technology challenges to develop commercially viable flexible displays that will have military applications. Currently, the commercial market is not significantly investing in flexible displays. Industry does see the potential market; however, the goals are ill defined. In addition, the initial cost of flexible-substrate displays compared to glass-substrate displays does not favor conversion without a ready market. Therefore, industry is not likely to convert to flexible-substrate displays for some time yet. As a result the current mode is to adopt and adapt with existing glass display technologies. The OFW and future combat systems (FCS) both can provide direction for this technology area and support it over the start up technologic barriers and on the path to full development. The Air Force is also developing flexible rollable wearable displays with features determined by the requirements for the integrated Battlefield Air Operations (BAO) kit for its special tactics combat controllers and the tri-Service Global Warfighter Information System (GWIS) for pilots. The lessons learned in the small volume Air Force BAO program, which is focused on the needs of a particular critical Air Force warfighting mission, will be made available to Navy SEALs and PM Soldier to assist designs for the higher volume Army OFW program. The GWIS program for pilots has many display capability needs in common with the BAO kit for the dismounts.

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RECOMMENDATIONS

AGED STAR on Displays (Approved by AGEDC 26 Nov 02)

Recommendation 1 – Access

DoD should take steps to mitigate the risk of its current, near-absolute reliance on off-shore sources of commercial displays and thin-film-transistor (TFT) active matrix backplane fabrication facilities. The U.S. should encourage off-shore manufacturers to establish domestic TFT LCD fabs. Supplier relationships, especially for avionics-grade and combat systems displays, should be carefully monitored to provide early awareness of potential disruptions. International projects and links between the DoD S&T community and off-shore display research institutions should be strengthened.

Recommendation 2 – Planning

DoD should establish a more rigorous mechanism to manage and coordinate available investments in displays—both planned and added—to optimize payoff to the warfighter. Such mechanism as is chosen would cause the maintenance and communication of defense-wide displays databases and roadmaps, the analysis and assessment of on-going programs, and the formulation and advocacy of recommendations.

Recommendation 3 – Investment and Payoff

DoD should invest in areas where military advantage is foreseen and government investment is timely. Display technology opportunities having defense-unique payoffs include thrusts in ultraresolution, true 3D, avionics, flexible, transparent, miniature, and intelligent (processor in display, efficient use of power and bandwidth). DoD should find innovative ways to close the information gap among warfighters that leverage the dynamic commercial market and academia to the maximum extent possible. DoD should have a coordinated Tri-Service display level of research funding comparable to that previously given to DARPA—a minimum of \$100 M/year is recommended. Specific investment opportunities include \$200M to create 25 Mpx devices and 300 Mpx systems, \$50M to create sparse symbol set true-3D monitors, \$50M for intelligent displays with embedded computing and sensing, \$75M for avionics cockpits, \$100M for flexible displays to enable rugged and wearable systems, \$25M for miniature displays in head-mounted and sight systems, and \$50M for basic research (over 4-5 years in each case).

Recommendation 4 – Transition

The services should fund engineering development and manufacturing technology to rapidly leverage commercial displays and to transition DoD display technology into warfighter configurations and platforms. The warfighter must not be technologically behind the kid playing video games. A minimum funding level of \$25M per year is suggested. Specific examples are noted below.²²

²² Concrete examples: (1) Digital micromirror device (DMD) technology was invented in the early 1990s based on \$10M DoD exploratory research funding from DARPA managed by AFRL; the technology then required some \$510M from TI private funding sources during the late 1990s to break into markets for presentation projectors, electronic cinema, and digital television, but just some \$40M from DoD to engineer and install DMD monitors in place of CRTs in AWACS crewstations. (2) Miniature active matrix liquid crystal display (uAMLCD) technology was invented in the mid-1990s based on \$30M DoD exploratory research funding from DARPA managed by SBCCOM; the technology then required substantial private funding during the late 1990s to enter qVGA markets for viewfinders and head-worn monitors, but just some \$13M from DoD to engineer green-SXGA uAMLCDs for use by Kaiser in the HMD system for the RAH-66; the SXGA is now being engineered into the HMD for the F-35.

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APPENDIX A

SPEAKER FINDING ATTRIBUTIONS

Table A-1. Cross-reference of Findings by AGED to Speakers.

Finding	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Speaker																		
Carolyn Hanna			X	X				X							X	X		X
Aris Silzars	X					X	X		X	X				X	X			
Mark Fihn						X	X							X				
Mark Bunzel									X					X				X
Albert Calvo					X													X
Arthur Behrens		X						X										X
R. Brandenburg								X	X		X							X
Geddes, Augustine								XX	XX		XX					XX		
Jim Niemczyk						X								X				X
Ollie Woodard						X							X	X	X			X
Pete Kazlas			X				X	X	X				X		X			
Julia Brown			X			X	X	X	X			X	X					
Kalluri Sarma	X	X	X		X			X				X		X	X	X		X
M. Kalmanash		X												X		X		X
Carl Vorst								X	X		X	X		X	X	X		X
Ray Liss	X	X		X	X			X				X		X	X	X		X
John Thomas	X	X	X		X			X		X			X	X	X	X		X
Al Jackson	X												X		X	X		X
Robert Tulis										X		X					X	
Robert Wisnieff									X									
Philip Heermann									X			X	X			X		
Sigurd Wagner								X				X	X			X		
Eliz. Downing								X	X			X				X		X
James Larimer									X	X	X	X						
H. Lee Task									X		X							
Webster Howard	X		X						X				X					X
Grouping	A	A	A	P	P	P	P	I	I	I	I	I	I	I	I	I	T	T

Finding Groupings

Access (A): 1-3

Planning (P): 4-7

Investments and Payoff (I): 8-16

Transition (T): 17-18

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APPENDIX B SPEAKER BIOS

Bios for Speakers

*DoD AGED STAR on Displays
Workshop 16-17 April 2002*

PLENARY PANEL

ANDREW C. YANG

Dr. Andrew Yang is Chairperson, DoD AGED Working Group C: Electro-Optics.

SUSAN TURNBACH

Dr. Susan Turnbach is Executive Director, AGED. She manages the interface of AGED to DoD and is Specialist for Electronics to the Deputy Under Secretary of Defense for Science and Technology.

DARREL G. HOPPER

Dr. Darrel Hopper is the Chair for Displays STAR and Author, JDL Reliance Displays Roadmap. He has led research to create, develop, and transition display technologies on a defense-wide basis since 1988. Dr. Hopper received his doctorate in 1971 in Physical Chemistry with a dissertation in quantum molecular physics. Following a one-year postdoc in biochemistry, he performed basic research in *ab initio* molecular electronic structure calculations until 1982 when he transitioned to applied research in electro-optics. He has worked as a Physicist at the National Air Intelligence Center, Professor of Electronics Engineering at the Air Force Institute of Technology, and, presently, a Principal Electronics Engineer at the Air Force Research Laboratory. Dr. Hopper has over 232 publications in organic chemistry, biochemistry, entomology, quantum chemistry, molecular physics, electro-optics technology, optical computing, and displays. He has chaired the Displays Track and edited the Cockpit Displays proceedings at SPIE for ten years and is a Director of SID. Email: darrel.hopper@wpafb.af.mil

CAROLYN HANNA

Ms. Carolyn Hanna is a Professional Staff Member, Committee on Armed Services, United States Senate. She was appointed to the Senate Armed Services Committee in March, 2001. She currently serves as lead staff to the Subcommittee on Emerging Threats and Capabilities and advises and supports the Members of the Committee in that capacity. Ms. Hanna provides oversight and review of the approximately \$10 billion in the Department's science and technology program, the test and evaluation program and the Service's unmanned systems. Prior to joining the Committee, Ms. Hanna served as Assistant Director in the Massachusetts Institute of Technology Washington Office. During her tenure at MIT, she served two years as co-chair of the Coalition for National Security Research (CNSR). CNSR is an advocacy organization comprised of universities, scientific associations and industry with a mission of advocating on behalf of a robust and stable defense science and technology program. Ms. Hanna was raised on various Strategic Air Command (SAC) bases in the USAF and swam competitively throughout her youth. She attended California State University, Long Beach on a swimming scholarship and graduated in 1990 with a BA in Political Science. In December, 2000 she earned a MA in Legislative Affairs from the George Washington University in Washington, D.C. Ms. Hanna lives in Washington, DC and occasionally finds her way to the local pool.
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ARIS K. SILZARS

Dr. Aris Silzars is the President of the Society for Information Display (SID). For the past several years, Dr. Silzars' career has been dedicated to the task of *taking new display technologies to market*. In support of this, he is currently working with a number of large corporations as well as several early-stage companies to help them develop nascent display technologies into successful products. He started his career as a research engineer but soon moved into managing groups of engineers (as large as 400) developing new display and solid-state technologies. This led to the management of both the development and manufacturing of displays and solid-state devices. Subsequently, he managed the overall business strategy and operations of organizations ranging from start-ups to businesses with over \$50 million in annual revenue. He has had the opportunity to work with companies as large and established as DuPont, as research oriented as the David Sarnoff Research Center, and as new as start-ups in the initial funding stages. Dr. Silzars received his B.A. in physics from Reed College in 1963, and his M.A. in physics and PhD in electrical engineering from the University of Utah in 1969. After completing his PhD studies, he joined the Watkins-Johnson Company to work on a variety of electron-beam addressed signal-processing devices. In 1974, his career interests took him to Tektronix where over the next thirteen years he held a variety of technical and business management positions to develop and implement display and solid-state technologies into Tektronix products. In 1989, he took on the responsibility of managing the start-up of a new electronic materials business for the DuPont Company and in 1994 he joined the David Sarnoff Research Center in Princeton, N.J. as Director of the Display Research Laboratory. He has been awarded eight U.S. patents and has dozens of published papers in major technical journals. He writes the monthly "A View from the Hilltop" column on various aspects of the display industry for *Information Display* magazine and has presented keynote talks and seminars on how display technologies will evolve and on the importance of manufacturing and marketing in bringing new display technologies to market. He is currently active in the Society for Information Display as its President and Chair of the Executive Committee. He is a past Senior Member of the IEEE. In 1993, he organized and chaired the successful First Annual Display Manufacturing Technology Conference. During 1994 and 1995, he was instrumental in building on the success of this conference to create a partnership between SID, SEMI, and USDC for a major new display industry event -- Display Works '96,'97, and '98.

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PANEL: Commercial Markets and Trends

MARK FIHN

Mr. Mark Fihn is Vice President of DisplaySearch. Mark joined DisplaySearch in August of 2000, after more than 14 years of computer components and LCD-related procurement experience at Texas Instruments and Dell Computer while living in the United States and Taiwan. He has been active in many display-related areas, most specifically in publicly championing industry-wide adoption of high-resolution, notebook LCD standardization, and video sub-system integration. Mark was educated at St. Olaf College, (Northfield, Minnesota); the American Graduate School of International Management, (Phoenix, Arizona); St. Edward's University, (Austin, Texas), and in the University of Texas at Austin's doctoral program in International Business. Email: markfihn@vvm.com

ROSS YOUNG

Ross Young is the founder and President of DisplaySearch. Prior to founding DisplaySearch, he served in senior marketing positions at OWL Displays, Brooks Automation, Fusion Semiconductor and GCA in the driver IC, flat panel automation, etch and strip and lithography markets respectively. Ross has been an invited speaker at more than 20 conferences and has had articles published in more than 15 periodicals. He was educated at UCSD's Graduate School of International Relations and Pacific Studies and Japan's Tohoku University. Email: ross@displaysearch.com

MARK BUNZEL

Mr. Mark Bunzel is General Manager, Intel Corporation, Visual Products Operation. Intel's Visual Products Operation is exploring the business opportunity for high performance visualization using clusters of off the shelf PCs equipped with consumer graphics cards. This work is based on a prototype product called Lightning 2 developed at Intel's Microprocessor Labs by a combined team from Stanford and Intel. Lightning 2 aggregates the visual output from each PC and provides complete pixel addressability for display on one or many displays. Because of the flexibility of the Lightning 2 product it is in consideration for high-resolution simulation applications, collaboration centers, and command and control video walls. Mark was formerly managing e-Business strategy for Intel's world wide sales and marketing. Prior to joining Intel 3 years ago, Mark was a Managing Director for PricewaterhouseCooper (PwC) in their management consulting unit advising the high tech and entertainment industry on the transition to digital media. Prior to PwC, Mark as Vice President of Sales and Marketing for Kaleida Labs, a joint venture of IBM and Apple computer. Mark is one of the pioneers of the evolution of graphics and multimedia applications on personal computers starting in the mid-1980's. He has been a consultant to IBM, Intel, Microsoft, Apple Computer, The Weather Channel, Knight Ridder and many others on graphics and multimedia standards. Mark is the former Chairman of the Interactive Multimedia Association (IMA), a Washington based trade organization that set many of the early standards for multimedia PCs. Mark is also a former board member of the Software Publishing Association. Mark is the co-author of "Multimedia Applications Development" published by McGraw-Hill, as well as a contributor to numerous books and magazine articles on digital media issues.

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ALBERTO B. CALVO

Al Calvo is a Principal Member of the Technical Staff for Northrop Grumman Information Technology (formerly Litton-TASC). He has over 28 years experience in applying quantitative analysis techniques to military acquisition programs. He has served as advisor to major government Source Selection panels addressing life cycle costs. He has specific qualifications in systems engineering, life cycle cost analysis, decision analysis, and wholesale logistics management of complex systems. He is the lead developer of Web-LCCA, a standard life cycle cost analysis model for military Display acquisitions. He is currently leading an internally-funded program at Northrop Grumman to design a Decision Information System for Procurement and Logistics Analysis (DISPLA). Al holds a Master of Science degree in Operations Research from M.I.T. and is a Certified Professional Logistician from the Society of Logistics Engineer.

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PANEL: Combat Systems Prime Contractors' Perspective

Arthur J. Behrens

Art is a Senior Specialist Engineer within the Core Avionics team of the Boeing Phantom Works Open Systems Architecture (OSA) organization. He is responsible for research and development with respect to implementation of open systems principles for displays-related technologies and internal applications of broad benefit to Boeing products. He has over 30 years of experience at Boeing and McDonnell Douglas in specification and development of military aircraft cockpit displays, display processors and digital map systems and was instrumental in development of these systems for AV-8B, A-12, F-15 and F/A-18. He began his career, in 1962, as a research engineer in the GSE department of North American Aviation's Space and Information Systems Division in Downey, CA, where he designed and developed the Digital Test Command System used for pre-launch checkout of the Apollo Command Module. He holds a Bachelor of Science Degree in Electrical Engineering from St. Louis University Institute of Technology in St. Louis. Email: arthur.j.behrens@boeing.com

Kevin W. Greeley

Mr. Kevin Greeley leads F-22 Air Combat Simulation development at Lockheed Martin Aeronautical Systems. Kevin recently co-authored a book entitled *Cockpit Displays: Test and Evaluation*.

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ROY C. BRANDENBURG

Mr. Roy Brandenburg has over 20 years of experience in the Military Electronics environment starting with the AN/UYK-43 computers and currently with the AN/UYQ-70. The experience ranges from software development to being one of the first AN/UYQ-70 architects. While assigned to the Q-70 functioned as the Industry lead for Technology Insertion. In that role lead the transformation from Cathode Ray Tubes to state-of-the-art AMLCD flat panels as the primary display device. Currently still assigned to the Q-70 as the Industry Lead for Technology Insertion investigating advanced display opportunities.

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JOHN M. GEDDES, JR.

Mr. John Geddes has been the Land Warrior Program Manager at Exponent since July 2000. Graduated B.S. Engineering from West Point in 1976 and M.S. in Operations Research from U.S. Naval Postgraduate School in 1986. Served in Army field artillery and ORSA positions for twenty years. Retired in 1997 after serving three years in U.S. Army's Louisiana Maneuvers Task Force and two years in Army Research Laboratory. Program Manager in General Dynamics Information Systems and technology consultant for PM Soldier Systems for SY Technology, Arlington, VA.

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SFC CHRIS AUGUSTINE

Sergeant First Class Chris Augustine entered the Army in 1984. Served in various duty positions in the 82nd Airborne Division, 25th Infantry Division (Light), and 6th Ranger Training Battalion. Continued service as a Combat Developer at TRAC White Sands Missile Range, Operation Research Analyst at TRAC Monterey and currently serves as Soldier Systems Integrator for the Training and Doctrine (TRADOC) System Manager Soldier, FT Benning GA.

PANEL: Display Component Manufacturers' Perspective

JAMES NIEMCZYK

Mr. Jim Niemczyk is Director of Product and Business Development at American Panel Corporation. He has been involved with the design, integration and test of displays for 15 years using both CRT and AMLCD technologies. These products have been installed as head down cockpit displays, large diagonal back end (mission crew) displays, and helmet mounted displays for many military and commercial platforms. At American Panel Corporation, Jim is responsible for the Product and Tooling/Automation Engineering group as well as New Business Development. Prior to that, Jim was the Avionics Division Manager for BarcoView and also Senior Program Manager at Avionic Displays Corporation. Jim has a Bachelor of Science in Mechanical Engineering from Michigan Technological University, Houghton Michigan, and a Masters of Engineering Management from Northwestern University, Evanston Illinois.

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OLLIE C. WOODARD

Mr. Ollie Woodard is Senior Project Manager, Advanced Display Development, Kopin Corporation. Mr. Woodard managed the SXGA display development for the Comanche RAH66 HIDSS HMD and managed preceding display projects funded by DARPA, NIST, NVESD and the US Army. He also

contributes display modeling, circuit design, characterization testing, and fabrication process development. Mr. Woodard was R&D manager at MCC doing applied research in electronic packaging materials, processes, equipment, and assembly and interconnect technologies used in advanced electronics packaging applications. One project included the application of Kopin's circuit transfer technology for wafer scale integration. As a Senior Engineer with IBM, he was Electronics Systems Manager, inventor and major contributor to the definition, design, development, and manufacturing of electron beam lithography systems used in quick-turn IC manufacturing. Mr. Woodard has an MSEE from Syracuse University and a BSEE from N.C. State University. Mr. Woodard has 12 patents issued and has authored more than 20 papers. Email: Ollie_Woodard@kopin.com

PETER KAZLAS

Dr. Peter Kazlas is Manager, Microelectronics Technology at E Ink Corporation. Dr. Kazlas received his B.S. and M.S. degrees in Electrical Engineering from Tufts University, and his Ph.D. in Electrical Engineering from the University of Colorado at Boulder. Dr. Kazlas has over ten years of industrial experience in displays and photonics technology development. He joined E Ink in 1999, and presently manages the Microelectronics Technology Group, which focuses on development of flexible paper-like displays for portable and wearable information appliances. Prior to E Ink, he held technology leadership and consultant positions at Charles Stark Draper Laboratory, Photonics Research, Vixel, and Cielo Communications. He has published several papers and holds patents on technologies related to displays, photonics and microelectronics. Email: pkazlas@eink.com

JULIA J. BROWN

Dr. Julia J. Brown is presently the Vice President of Technology Development at Universal Display Corporation where she is responsible for the technical direction of the company. From November 1991 to June 1998, she was a Research Department Manager at Hughes Research Laboratories where she directed the pilot line production of high speed Indium Phosphide-based integrated circuits for insertion into advanced airborne radar and satellite communication systems. She received her B. S. in Electrical Engineering from Cornell University (1983) and then worked at Raytheon Company (1983-1984) and AT&T Bell Laboratories (1984-1986) before returning to graduate school. Dr. Brown received an M.S. (1988) and Ph.D. (1991) in Electrical Engineering/Electrophysics at the University of Southern California under the advisement of Professor Stephen R. Forrest. Dr. Brown has co-authored over 125 publications and conference presentations in the fields of high speed compound semiconductor electronic/optoelectronic device, micro-electro-mechanical systems (MEMs) and organic light emitting devices (OLEDs). Dr. Brown has served as an Associate Editor of Journal of Electronic Materials and as an elected member of the Electron Device Society Technical Board. She co-founded an IEEE-sponsored international engineering mentoring program. She is a Senior Member of IEEE and is presently an active member of the Society of Information Display. Email: jjbrown@universaldisplay.com

PANEL: Display Subsystem Integrators' Perspective

KALLURI R. SARMA

Dr. Kalluri R. Sarma received his Ph.D. degree in Materials Science from the University of Southern California, Los Angeles, CA. He is a Principal Research Fellow at Honeywell Aerospace Electronic Systems, since 1986. His responsibilities include evaluation of emerging display technologies, and research and development of advanced display devices and systems for avionic applications. His research and inventions are incorporated into AM LCD products for Boeing 777, 737, several business jets and military aircraft. He received the prestigious H. W. Sweatt award from Honeywell in 1993 for his pioneering work on AM LCD viewing angle improvements. Prior to this, he was a Member of Technical Staff at Motorola with contributions in the areas of plasma processing, laser recrystallization, silicon solar cells and semiconductor materials and devices. Dr. Sarma has published over 40 papers in technical

journals, has been awarded 26 U.S. patents, and has several pending patents. He served as a reviewer for many technical Journals such as IEEE, and SID. He also served as a reviewer for NSF and DOE proposals and programs. Email: kalluri.r.sarma@honeywell.com

ERIC ELISON

Mr. Eric Elison is Manager at Honeywell Defense & Space Systems in Albuquerque NM. He is demonstrating a 14-in. commercial display being integrated for use in the cockpits of the Gulfstream V and F/A-18E/F aircraft.

MICHAEL KALMANASH

Michael Kalmanash is Principal Engineer at Kaiser Electronics, a Rockwell Collins Company in San Jose, California. Mr Kalmanash has over 30 years experience in the development of advanced technology for high performance military and avionics displays. He has been employed at Kaiser Electronics for the past 20 years, where he played a pivotal role in the introduction of the KROMATM color display technology for the F-18, the initial development of AMLCD technology as implemented in the F-22, F/A-18 and F-15 aircraft. For the past five years his efforts have been concentrated on the development of advanced technology for high performance rear projection avionics displays. Mr Kalmanash holds 20 US patents, and has authored 11 technical papers. He is active in SID and SPIE. Email: kalmanashm@kaisere.com

CARL VORST

Mr. Carl Vorst is a Boeing Associate Technical Fellow serving as the Principal Investigator for Display System Development in the Boeing Aircraft and Missiles Training Systems Research and Development organization. He is responsible for research and development of next generation display systems for flight simulation, and often serves in a consulting role to other Boeing components and to industry. He has over 30 years of experience in the field and was a key player in development of the first Digital Image Generation System receiving FAA approval for pilot training. He is a holder of three patents and has three pending. His most recent accomplishment was development of the low cost, wide field of view display system used for the Longbow Crew Trainer. Carl received his Bachelor of Science degree in Electrical Engineering from the University of Missouri at Rolla and his Masters in Business Administration from Lindenwood University. Email: carl.j.vorst@boeing.com

RAYMOND L. LISS

Mr. Ray Liss is the Manager of Display Programs at Rockwell Collins and the Chairman of the Military Avionic User Group of the United States Displays Consortium (USDC). He has been involved in display technology for the last 18 years. With an academic background in Chemistry, Ray started his military display work as a Development Manager for Hoffman Engineering, Stamford CT where he contributed to the development of a process to integrate an edge-less, thick film, electroluminescent lamp into MIL-P-7788 type keyboards. He went on to work on night vision lighting-compatible filter materials, and eventually test equipment for Night Vision Goggles, Helmets, Visors and HUDs. Ray was employed at OIS Optical Imaging Systems as they were bringing up the new Northville Michigan Plant. He has spent the last 5 years at Rockwell Collins, Cedar Rapids Iowa working AMLCD and Display requirements for Military and para-Military applications. Ray has been the Chairman of the USDC Military Avionics Users Group for the last 4 years, and is a member of the USDC Board of Directors. Email: rliss@collins.rockwell.com

JOHN THOMAS

Mr. John Thomas has worked in the military display development field as a developer and product manager for over 20 years and is currently Manager for Display Technology at General Dynamics Canada. Prior to this, he worked with Canadian Marconi Company, developing displays for aircraft cockpit applications. His primary display-related interests lie in the area of adapting commercial display

components for use in harsh and military environments and in optimising the cost/optical performance of military displays. Email: john.thomas@gdcanada.com

AL JACKSON

Mr. Al Jackson is an employee of ELCAN a Raytheon Company. He has over 26 years in the Defense Electronics industry. His present positions at Raytheon are Digital Display Group Business Development Manager and CLADS Program Manger. Al has worked with all branches of the military to solve display issues. He has been involved in the production of DLP based displays since 1995. Al holds a Bachelor of Science degree in Electrical Engineering from Mississippi State University and Master of Science degree in Electrical Engineering from Southern Methodist University. Email: ajackson3@raytheon.com

PANEL: Display Research Perspective

ROBERT W. TULIS

Dr. Robert Tulis is the Program Manager for displays at the DARPA Microsystems Technology Office. From 1973-1999, Dr. Tulis developed and commercialized photographic materials and systems, display components, and manufacturing technology at Polaroid Corporation in Cambridge, Massachusetts. His most recent responsibilities, as Senior Corporate Program Manager, Business Director, and Divisional Research Director, included the design, manufacture, and marketing of Optical Films for LCD and custom OEM applications and developing strategic, commercial partnerships worldwide. He has significant general management, as well as technical experience, developing breakthrough products and selling to consumer and business-to business markets globally. Dr. Tulis received his Ph.D. in Organic Chemistry from the Massachusetts Institute of Technology in 1972 and his B.S. in Chemistry from Boston College in 1968 where he was a Presidential Scholar in the Honors Program. He also served in the 26th Yankee Division, Massachusetts Army National Guard from 1968 to 1974. Email: rtulis@darpa.mil

ROBERT L. WISNIEFF

Dr. Robert Wisnieff serves as the senior manager of the Advanced Display Technology Laboratory. The Display Fabrication, Display Test, Display System and Liquid Crystal research groups at the IBM TJ Watson Research Center report to him. He coordinates activities between the Display Business Unit and research groups at the Tokyo Research Laboratory, Almaden Research Center, Watson Research Center and the Zurich Research Laboratory to maximize the effectiveness of IBM's flat panel display related research programs. The Advanced Display Technology Laboratory initiates new programs of research in the materials, processes, design and fabrication of active matrices, materials and processes for electro-optic transducers such as liquid crystal and organic light emitting diodes, and in the design and implementation of new display systems. Recent focus areas include high-resolution/high content displays which has resulted in the Roentgen 5 million pixel display and the Bertha 9 million pixel display systems, active matrix organic light emitting diode displays and low cost manufacturing processes for liquid crystal and TFTs. Advanced Display Technology Projects span multiple research sites and are integrated into the advanced development activities of the Display Business Unit. Dr. Wisnieff joined IBM after earning a Ph.D. in applied physics and has spent his career with IBM Research. Prior to assuming his present position he spent a year in a staff position for the Research Vice Present of Strategy and Planning. Prior to that position, he pursued applied research and held first level management positions in the flat panel display research program. His research contributions include mathematical modeling of the limits of active matrix liquid crystal display performance, including software to model the front of screen performance of displays and invention of an array tester to allow pixel level fault isolation after active matrix fabrication and prior to cell assembly. Dr. Wisnieff was raised in New York and Connecticut, studied at Tufts University, where he received a BS in Mechanical Engineering and Physics in 1980, and earned a Ph.D. in Applied Physics from Yale University in 1986. He is a member of the IEEE and SID.

He has served as Program Chair and General Chair of the SID Symposium, Secretary and Treasurer of the SID and has served on program committees for the IEEE and SID. He received an IBM Corporate Award for the invention of the TFT array tester in 1993. March 1, 2001. Email: wisnieff@us.ibm.com

PHILIP D. HEERMANN

Dr. Philip D. Heermann completed his graduate studies at the University of Texas at Austin in 1992. He joined Sandia National Laboratories in 1993. He is currently the program lead for the ASCI/VIEWS (Visual Interactive Environment for Weapons Simulation) at Sandia, responsible for developing and deploying the hardware and software systems for managing and visualization terabyte scale data sets. Also, he has served as the ASCI/VIEWS tri-lab lead representing Los Alamos, Sandia and Lawrence Livermore National Laboratories. He has published 22 peer-reviewed papers and is the manager of the Data Analysis & Visualization department, a research and development group with 18 Sandia staff and contractors. Email: pdheerm@sandia.gov

SIGURD WAGNER

Professor Sigurd Wagner is helping lay the groundwork for the new industry of macroelectronics by developing concepts, materials, devices and processes for large-area electronics. He received his Ph.D. from the University of Vienna in 1968, and came to the U.S. as a postdoctoral fellow at Ohio State University. From 1970 to 1978 he worked at Bell Telephone Laboratories on semiconductor memories and heterojunction solar cells, and from 1978 to 1980 he was Chief of the Photovoltaic Research Branch of the Solar Energy Research Institute in Golden, CO. Since 1980 has been Professor of Electrical Engineering at Princeton University. Email: wagner@princeton.edu

ELIZABETH DOWNING

Dr. Elizabeth Downing is the Winner of Technology and Innovation awards from *Discover Magazine*, *Industry Week Magazine*, and *Saatchi & Saatchi*, and recently featured along with Hillary Rodham Clinton, Madeleine K. Albright, and Sandra Day O'Connor in *Feminine Fortunes – Women of the New Millennium*. Elizabeth Downing is well known for her contributions to the field of volumetric visualization. Holder of more than a dozen patents on optical and laser-based instrumentation, Downing has not only developed a paradigm shifting technology, but has worked to channel it into key initial markets where time-critical visualization of volumetric data can mean the difference between life and death. A mechanical engineer specializing in systems integration by training, Downing not only conceived of the basic concepts, but has worked to develop the material processing capabilities and has integrated the optical systems to create the world's first 360-degree walk-around three-dimensional display. Founded in 1996 with the help of key technical and business experts, her company, 3D Technology Labs (3DTL) has meticulously pushed the performance envelope of a challenging new visualization frontier. In a business climate where IPO mania has often replaced common business sense, 3DTL has methodically used government funding (NIST-ATP, DARPA-BAA, SBIRs) to mitigate technical risk, ensuring that key technical barriers to commercialization could be successfully addressed. As a result, 3DTL is ready to embark on the next round of challenges, namely *transition*, to begin tailoring, testing, and evaluating crossed-beam volumetric displays for the Department of Defense. Email: eliz3d@hotmail.com

JAMES LARIMER

Dr. James Larimer joined NASA's Ames Research Center in 1987. He has actively pursued display research during his tenure there. His NASA team developed a CAD tool for designing electronic displays that has been used extensively in the display industry. The National Academy of Television Arts and Sciences recently awarded an Emmy for the CAD tool's human vision model, developed collaboratively with the Sarnoff Corporation, as a metric for image quality. Dr. Larimer received a Ph.D. degree in experimental psychology from Purdue University. He was a postdoctoral fellow at the Human Performance Center at the University of Michigan, a Professor of Psychology at Temple University in

Philadelphia, Chairman of the Department of Psychology at Temple University, and Director of the sensory Physiology Program at the National Science Foundation before joining NASA. He is a member of IEEE, SID, SPIE, SMPTE, IS&T, OSA, and AAAS. He is past Chairman of the Bay Area Chapter of the Society for Information Display, a SID program Committee Member since 1991, a member of the SID Executive Board, and a SID Regional Vice President. Email: jlarimer@mail.arc.nasa.gov

H. LEE TASK

Dr. Lee Task is a Senior Consultant to the Air Force Research Laboratory Visual Display Systems Branch via Sytronics Inc. He is a retired ST (Senior Executive – Technical) from the Air Force Research Laboratory, where he served in the scientific research area for 31 years, including the position of Chief Scientist of the Armstrong Aerospace Medical Research Laboratory (now part of the Air Force Research Laboratory). Dr. Task holds a Ph.D. in Optical Sciences from the University of Arizona Optical Sciences Center, has published more than 100 journal articles, proceedings papers, and technical reports and has been granted 45 US patents. His research specialties involve the optical and visual aspects of human systems interface with emphasis on display image quality, night vision devices, vision through aircraft transparencies, helmet mounted displays, and vision in space. He is a member and past editor of the journal of the SAFE Association, a member and on the editorial board for the Human Factors and Ergonomics Society, a member and current chairman of the American Society of Testing and Materials (ASTM) of main committee on Aerospace and Aircraft (F7) and the subcommittee, F7.08, on aerospace transparencies. He is also a Fellow of ASTM. Email: lee.task@wpafb.af.mil

WEBSTER E. HOWARD

Dr. Webster Howard received his B.S. from Carnegie-Mellon University and his A.M. and Ph.D. from Harvard University, all in Physics. He joined IBM in 1961 at the T. J. Watson Research Center as a Research Staff Member. At IBM he worked for 12 years in semiconductor physics, including pioneering work on 2-dimensional electron gases in Si inversion layers and on semiconductor superlattices. From 1973-93, he focused on display technology, managing projects in plasma displays, thin film electroluminescence, CRTs, and TFT LCDs. The latter project led to the formation of DTI, the joint venture between IBM and Toshiba. In 1993, he joined AT&T, as a Director in the High Resolution Technologies division of AT&T Global Manufacturing and Engineering. He also served as a consultant to the Display Research Department of AT&T Bell Laboratories. When AT&T/Lucent Technologies terminated its display activity in 1996, he joined eMagin Corporation, where currently he is Chief Technology Officer. Dr. Howard is a Fellow of the American Physical Society, the IEEE, and the Society for Information Display, as well as being a member of Sigma Xi. He is a former President of the Society for Information Display. In 1981, he was a co-recipient of the Wetherill Medal of the Franklin Institute, for his work in 2-D electron gases. He is a former member of the IBM Academy of Technology. Email: WHoward494@aol.com

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APPENDIX C

MILITARY DISPLAY MARKET SYNOPSIS

The defense-wide military display market has been analyzed for some years by AFRL. The project is dynamic and begins each spiral with an inventory of all DoD weapons systems and platforms that are either currently fielded or funded for engineering development, then adds foreign military sales of these systems. Only platforms that are deployable to one of the nine Combatant Commanders, or are used by service operating commands to prepare capabilities for deployment, are included. Then every display located anywhere within each system or platform is identified and characterized by the number of units, size, technology, performance specification parameters, et cetera. Summaries approved for public release have been published.^{23,24} The full report is available to qualified requestors:

Daniel D. Desjardins and Darrel G. Hopper, *Military Display Market: Third Comprehensive Edition*, AFRL-HE-WP-TR-2002-0139, August 2002, 594 pp. Send requests to AFRL/HECV, Wright-Patterson AFB OH 45433-7022.

Defense displays total 438,882 units that range in size from 13.66 mm to 4.543 m (0.5 in. to 15 ft.). Some 1163 individual sizes exist, of which 715 are unique to just one DoD program. The DoD program offices might leverage existing or planned program acquisitions across the services to reduce non-recurring engineering costs and to maximize volume purchasing for both new systems and upgrades to systems already fielded. It is recognized that, short of an instrument panel re-design (partial or full), existing crewstation configuration imposes a cost and schedule limitation to the latitude any one program faces in terms of display size conversion. The wide range of sizes in DoD use is a result several phenomena. For commercial units, both ruggedized and unruggedized, the rapidly changing offerings of the commercial market is an important factor; sizes used are those available at the time of a procurement action. For all systems, a lack of coordination amongst program offices continues to be a factor as well; these programs are islands unto themselves driven by differing cultures, timelines, and requirements.

Some 40% of DoD displays are custom designed and fabricated (esp. for cockpit avionics). Some 60% of DoD displays are designed for consumer products; many are ruggedized, but notable exceptions exist where ruggedization is not necessary. Military displays are summarized in Table C-1.

Table C-1. Defense Displays That Are Currently Fielded or Programmed for Fielding.

Category	Platforms	Sizes	Displays	High Info. Content*	Design Class(es)
Defense-wide	438	1163	438,882	75.8 %	Custom, Ruggedized, COTS
Aircraft cockpits	272	416	176,744 (40.3%)	83.2 %	Custom-design

*High information content displays are defined as those having resolution (spatial, grayscale, temporal) over 320x240 pixel/image, 24 bit/pixel color, 30 frames/sec, which is capable of showing NTSC video.

²³ Darrel G. Hopper and Daniel D. Desjardins, "Analysis of the Defense Display Market," *SID Information Display*, Vol. 18, pages 40-44 (April 2002).

²⁴ Daniel D. Desjardins and Darrel G. Hopper, "Military Display Market: Third Comprehensive Edition, in *Cockpit Displays IX: Displays for Defense Applications*, SPIE Vol. 4712, pages 35-47 (August 2002).

An analysis across all platforms by technology is illustrated in Figure C-1. Some 66% of total DoD displays are implemented with some form of FPD (mostly AMLCD) and 33%, with CRTs. The CRT share of the military display market is declining rapidly in favor of FPDs. Most technology insertion opportunities will be for various types of AMLCDs and DMDs over the next 10 years. However, CRTs will remain an important component of the installed base. Other FPD technologies (LED, EL, plasma, etc.) appear destined to remain minor players. Beginning about 2005 some future technologies, such as OLED, VRD, and SSLP may mature enough for acquisition programs.

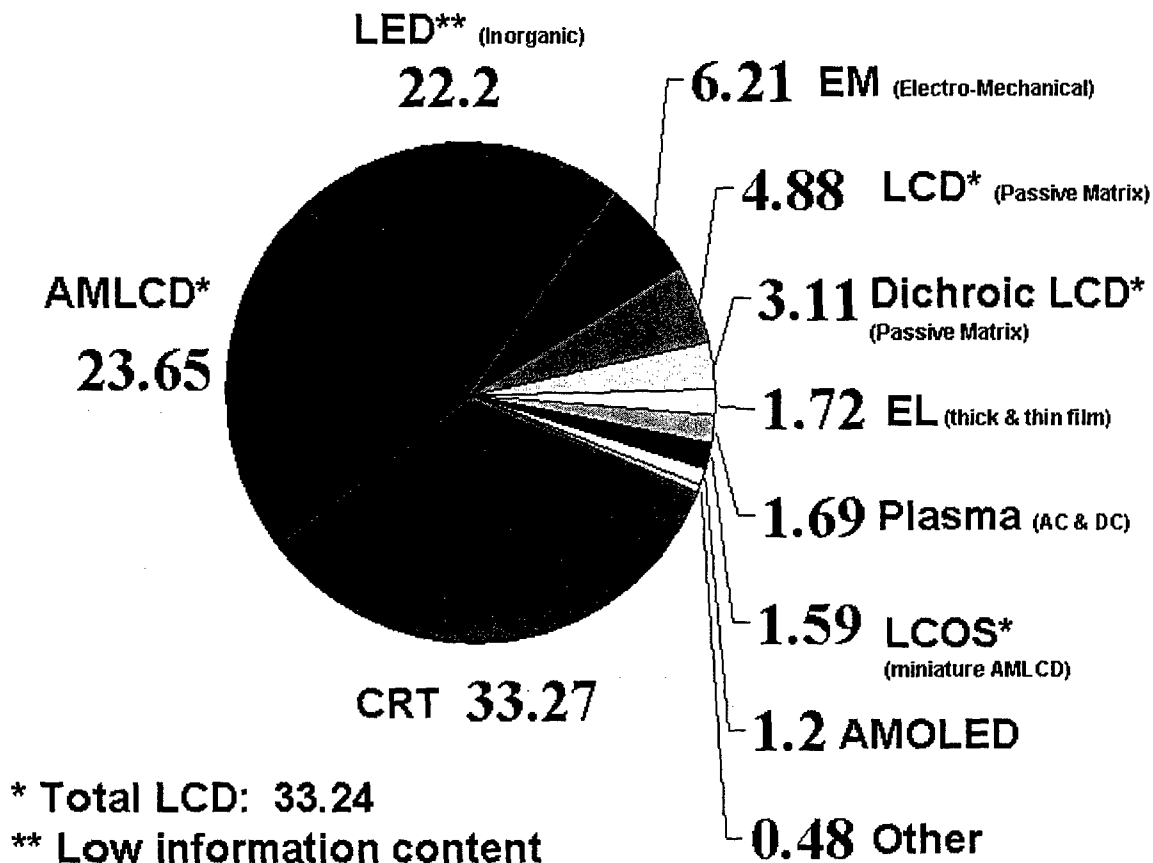


Figure C-1. Defense Display Percentage Breakout by Device Technology.

The installed base of military displays will grow over the next life cycle of current systems even as newer technologies replace the old. More displays per person will become one means by which DoD achieves its goal of revolutionary improvements in communication, information connectivity, and warfighter productivity. However, the present inventory of some 438,882 displays will also be largely replaced over the next life cycle; it can be anticipated that much of the current inventory will require technology upgrade for affordability via form-fit-function or panel re-design programs. Affordability is driven by the dramatically improved MTBF rate of FPDs versus older technologies. The MTBF for FPDs is some 13X that of the old technology (CRT and electromechanical) displays.

Performance specifications are also analyzed in detail in the AFRL military display market study program. The toughest applications are the point-of-the-spear systems for combat and special forces. The performance parameters result from a long chain of contracts: the initial government's system performance specification is levied on prime contractors, who levy component subsystem specifications their display and controls subcontractors, who levy yet more detailed and restrictive requirements on their display subassembly contractors, who then do the same to their display panel manufacturers. Each contracting level asks for more than it needs to ensure it meets is contractual obligation. Often, the panel manufacturing company making the display device per se has no way to communicate with the government to understand if it is being asked to make a display with realistic performance.

Aircraft cockpits pose the most stress on state-of-the-art display technology. All cockpit displays are produced in custom fab runs. Compatibility with night vision conditions, devices and systems generate stress in other parameters. The cockpit display technology of choice is the avionics-grade AMLCD. Most new cockpit instrument panel displays are large, so-called "direct view," transmissive AMLCD devices, which are an avionics-grade of the same TFT AMLCD technology use in notebook computers, information appliances, and LCD digital television. Also, reflective miniature AMLCD devices in a rear projection design are used for one display size each in the F-22A, F/A-18E/F, and F-35. Transmissive miniature AMLCDs are used in the RAH-66 helmet system. Small and miniature CRTs and IITs are still in use in HUDs and in fielded helmet systems.

Mission crewstations electronics packages are implemented via consoles inside of vehicles ranging from aircraft, ships, submarines, trucks, and spacecraft. The vehicle or platform in which the console is installed, including custom-design consoles, usually provide most of the ruggedization and controlled environment necessary to permit a non-military, commercial design display to be used even the vehicle or platform itself is immersed in a severe environment (e.g. in space, in the air at 40,000 ft., on/under the high seas, or amid desolate terrain ranging from mountains to jungles to deserts).

Command posts and control centers may have an environment ranging from that of a tent to that of an office building. In the former case the environmental considerations are a mixture of the cockpit and mission crewstation described above. Ruggedization may be necessary but custom design is typically not. In the case of a building, no environmental concern beyond civil office structures is typically needed except to provide for security and hardened rooms below ground. One direction in which command posts and simulators of the future may stress technology is toward ultra-resolution (10-300 megapixel display systems). Such ultra-resolution display technology is just now coming into existence for applications in various fields of business, science, medicine, engineering, as well as defense, to visualize large databases.

The industrial base strategy for DoD displays is based on research in the US and production in Asia. The display device installed in cockpits is almost invariably a specialty design intended just for avionics use and fabricated via a custom run in an Asian fabrication facility. In some situations, custom-manufactured displays appear in applications other than aircraft cockpits: the M1A2 Abrams SEP commander's forward looking infrared (FLIR) display, based on TFEL technology, is an example. These avionics displays, plus a few additional custom-design displays in other vehicles, are virtually all AMLCDs; they comprise about 40% of total DoD displays.

Some 60% of DoD displays are based on consumer product-driven designs. For example, the ruggedization approach has been used for some 41 types of portable laptop displays or transportable PC displays for dismounted soldiers comprising 47,761 ruggedized commercial display units (58.2% AMLCD; 31.5% dLCD). The direct use of products designed for the consumer electronics market includes installation on 17 different classes of Navy ships and boats entailing some 30,236 fully consumer designed displays (96.9% CRT) that are mounted in environmental, shock and EMI isolation consoles.

Engineering efforts are underway that attempt to use a ruggedized COTS display component rather than custom-designed display component in cockpits. Only time will tell if the underlying consumer-driven technology has improved enough for the ruggedized COTS approach to (a) successfully achieve the performance specification in the integrated flight instrument and (b) subsequently work after installation in fielded service to the satisfaction of regular flight and maintenance crews during the course of regular missions. Thus far, no one has provided evidence of passing both tests (a) and (b) except with a custom-design approach for the avionics display component. Several programs (e.g. C-130H for ADI, HSI, radar display) have had to pay EMD and procurement costs twice for the same LRU because promises that a ruggedized COTS approach would work proved false in fielded service.

Most displays being purchased are based on AMLCD technology. All of the AMLCD display manufacturing facilities at or greater than \$1 billion capitalization are located in Korea, Japan, or Taiwan. All plasma manufacturing also takes place in these countries. Custom avionics-grade AMLCDs are produced by a defense company purchasing fabrication time on one of the \$1B commercial production lines in Asia. Teams of US avionics and Asian AMLCD manufacturers include: American Panel Corporation in Alpharetta GA with LG.Philips-LCD in Kumi, Korea; Planar America in Beaverton OR with AU Optronics in Hsinchu, Taiwan; Honeywell with Philips Components in Kobe, Japan; Rockwell Collins with Sharp in Tenri, Japan; and International Display Consortium with NEC in Japan. Avionics display manufacturing also occurs for Sextant Avionique with Thales in Grenoble, France. The minimum order for a custom avionics display manufacturing run is typically 1,000 units.

Ruggedized displays based on consumer-designed products involve commercial offerings that change every few months in response to pressures from high volume consumer electronics OEMs. Occasionally, these changes require a defense program or contractor to make a "life-time" buy or re-engineer the military product. This continual change process complicates logistics by increasing configuration complexity in fielded fleets. Recurring lifetime buys and growing sustainment complexity must be balanced, on a life-cycle basis, against the cost of a custom run.

Some display manufacturing does, in fact, occur in the US. One example is the manufacture by Texas Instruments in Dallas, Texas of the DMD Digital Light Processing® light engines sold world-wide to companies that integrate them into projectors for the presentation, electronic cinema, and digital television markets. TI works with a Raytheon unit located within its complex near Dallas to produce DMD products for 21-in. E-3A AWACS crewstations, a 30-in. map display on the Seawolf submarine, a 30-in. variant of the Navy UYQ-70 workstation for shipboard combat information centers, and a tiled wall display system in a command center bunker in the DC area. Also, Planar in Beaverton OR manufactures thin-film electroluminescent displays for a variety of ruggedized applications and at least one custom-design application (FLIR display in M1A2 SEP). Several steps in the manufacture of reflective miniature AMLCDs (LCOS) devices and light engines occur in the US. Passive LCD displays are manufactured in the US by several companies, including Sharp, Planar, and Kent Displays. And CRTs are still manufactured in the US by several specialty product companies and by several Asian companies with US-based factories.

An analysis of all defense displays by the level of information content is informative. Two categories are used: low information content (LIC) and high information content (HIC). The LIC displays present only characters, numbers, and fixed symbols and represent 24% of all DoD displays. The HIC displays are capable of presenting arbitrary graphics and video (complex computer generated graphics and video from sensors or image generation systems) and represent 76% of all DoD displays. The LIC breakout by platform group is as follows: 49% in hand-held radios; 27% in aircraft cockpits; 11% in ground vehicles, 10% in surface vessels, 1% in submarines and 1% maintenance and command and control. The LIC breakout by display technology is as follows: 91.25% LED; 1.40 % LCD; 3.29% dLCD, 3.25% gas plasma; 0.57% EL; 0.01% TFEL; and 0.23% EM/LED hybrid.

APPENDIX D

GLOSSARY

AAAV	Advanced Amphibious Assault Vehicle (USMC)
ABCCC	AirBorne Command and Control Center (e.g. C-130E ABCCC), a tactical C-130 pallet
Add	Congressional addition to PBR specifying to the administration an effort to be executed
AFRL	Air Force Research Laboratory
aka	also known as
AM	Active Matrix – implemented with various circuit switching devices like TFTs or MIMs
AMLCD	Active Matrix Liquid Crystal Display
AMOLED	Active Matrix Organic Light Emitting Display
AMEPID	Active Matrix Electro-phoretic Ink Display
AMRDEC	Aviation & Missile Research, Development & Engineering Center, part of RDECOM
A&M	Aircraft & Missiles
AOC	Air Operations Center
APOM	Amended POM; POM begins in every even year; APOM makes adjustments in odd year
AR	Anti-reflecting (film, coating)
arc min	Minute of Arc, one-sixtieth of an arc degree (where a full circle = 360 arc degrees)
ARL	Army Research Laboratory; includes SEDD and ARO directorates
ARINC D	Aircraft cockpit display size, 8x8 in. instrument panel area (viewable area ~6.7x6.7 in.)
3ATI	Air Transport Indicator, 3x3 in. instrument panel area (viewable area ~2.2 x 2.2 in.)
5ATI	Air Transport Indicator, 5x5 in. instrument panel area (viewable area ~4x4 in.)
ARL	Army Research Laboratory
ARO	Army Research Office, a directorate of ARL
ASC	Aeronautical Systems Center
ASCI	Advanced Strategic Computing Initiative (at three DoE labs: SNL, LLNL, LASL)
ASP	Average Selling Price
ATD	Advanced Technology Development (an S&T maturation and transition program)
ATSC	Advanced Television Systems Committee
AVVV	Advanced Amphibious Assault Vehicle (USMC)
AWACS	Airborne Warning and Control System (e.g. E-3 Sentry AWACS)
B	Byte
Bandwidth	Examples of bandwidth input to display devices (from camera, computer, or comm. link):
- qCIF+	0.021 Gbps (38,720 pixels x 18 bits/pixel x 30 Hz) (Application: cell phones)
- qVGA	0.055 Gbps (76,800 pixels x 24 bits/pixel x 30 Hz) (Application ~NTSC TV)
- SXGA	1.887 Gbps (1,310,720 pixels x 24 bits/pixel x 60 Hz) (Apps: workstations)

- HDTV720	1.327 Gbps (921,600 pixels x 24 bits/pixel x 60 Hz)
- HDTV1024	2.920 Gbps (2,027,520 x 24 bits/pixel x 60 Hz)
- QUXGAW	9.069 Gbps (9,216,000 pixels x 24b/pixel x 41 Hz)
- 16SXGA	40.265 Gbps (20,971,520 pixels x 24 bits/pixel x 80 Hz)
- Human Eye	1.2 Gbps (upper bound estimate by Larimer) – for 2° about instantaneous gaze direction
- Real World	3.3 Tbps (lower bound estimate by Hopper) – sampled continuously by human eye-brain
BAO	Battlefield Air Operations
BCA	Boeing Commercial Airplanes (BCA)
Bluetooth	Wireless standard IEEE 802.15.1 (less than 0.5 Mbps)
Brightness	Complex metric comprising luminance and contrast; often used to mean luminance
Budget Activity	Basic Research (01); Applied Research (02); Advanced Technology Development (03), Dem & Val (04); Engineering & Mfg Dvmt (05), Operational System Development (07
by	byte
byte	8 bits
C2D	Command & Control Directorate, U.S. Army CERDEC
CADRT	Computer Aided Dead Reckoning Tracer (NAVSEA program)
CAGR	Compound Annual Growth Rate
candela	Base unit applicable to photopic, scotopic, and mesopic domain quantities viewable by human eye, and for this purpose is defined as the luminous intensity of a source emitting 540 GHz radiation at an intensity of $683^{-1} \text{ w sr}^{-1}$ in a given direction
CAOC	Combined Air Operations Center
Cardinals	Chairmen of HAC, SAC, and their 13 respective subcommittees
CASCOM	Combined Arms Support Command (US Army)
CBD	Crossed-beam volumetric display
CDT	Cathode Display Tube (use in monitors)
CERDEC	Communication-Electronics Research, Development and Engineering Center, part of U.S. Army RDECOM; includes NVESD and C2D directorates
CIF	Cell phone Interface Format
CMOS	Complementary Metal Oxide Semiconductor (min. pwr circuits pairing PMOS & NMOS)
CP	Cell Phone (syn. Mobile Phone)
CPT	Cathode Picture Tube (used in TVs)
CR	Contrast Ratio $\equiv (L_{\max} - L_{\min}) / (L_{\max} - L_{\min})$
CRT	Cathode Ray Tube
CSF'	Contrast Sensitivity Function
CSTN	Color STN
CVC	Combat Vehicle Crew
cy	cycle, e.g. spatial line pair, one dark line adjacent to one white line

cycle	one repetition of a spatial or temporal waveform (basis function)
DARPA	Defense Advanced Research Projects Agency
Development	
- Advanced	Demonstration prototype of a real-world application; 6.3; TRL 6-7 (of 9)
- Engineering	Build a production prototype, 6.4; TRL 8-9 (of 9)
Direct-View	Real image physically located where eye perceives it to be; many persons can see image; Image created in, or projected to, physical plane at which viewers' eyes focus; Examples: CRT, FPD (LCD, PDP, VFD, EL, LED, OLED, EPID), Projection (RP, FP)
Display Device Size Class:	
- Micro	Small wrt human scale, indirect-view (non-real virtual image, viewable by just 1 person)
- Normal	Human scale, direct-view (real image, viewable /w unaided eye, focus at plane of image)
- Jumbo	Very large wrt human scale, direct-view (big pixels, seen at a distance in public areas)
dLCD	dichroic liquid crystal display
DLP	Digital Light Processing, a Texas Instruments trademark for DMD-based light engines
DMD	Digital Micro-mirror Device (DMD), first commercially successful MEMS device
DPA	Defense Production Act, Title III for creation of domestic capacity for critical "materiel"
DPAT	Display Process Action Team (Boeing Enterprise-Wide activity)
dpi	Dots per inch, metric for detail used in printing; sometimes used to mean pixels per inch
DRS	DRS Laurel Industries
DV	Direct-View
DVI	Digital Video Interface (standard)
EAP	Electro-Active Polymer (program at DARPA Defense Science Office)
EPID	Electro-Phoretic Ink Display (non-video rate, bistatic reflective display technology)
F/A-18C/D	Hornet
F/A-18E/F	Rhino (name used on board carrier to avoid confusion in voice communications)
F/A-22	Raptor
F-35	Joint Strike Fighter (USAF, USN, USMC, RAF)
fab	Fabrication Facility; high capitalization (\$1-2B) plant for backplane TFT manufacturing; typically refers to an AM TFT LCD, but also AM TFT OLED or AM TFT EPID facility
FAA	Federal Aviation Administration
fc	foot-candle, an archaic unit for illuminance (see "Illuminance" below)
FE	Field Effect (method by which LC is modulated)
FED	Field Emission Display (usual), Flat Emissive Display, or Flexible Emissive Display
FireWire	Nickname for IEEE1394 digital interface standard for cabled data (runs up to 1.6 Gbps)
fl	foot-Lambert, an archaic unit of luminance (see "Luminance" below)
FLIR	Forward Looking Infra-Red, imaging of 8-14 nm band of electromagnetic spectrum
FOLED	Flexible OLED (see similar sounding acronym, PHOLED)

FP	Front Projection
FPD	Flat Panel Display
FPDI	Flat Panel Display Initiative (1994-1998 effort to create domestic FPD mfg. capacity)
FMS	Foreign Military Sales
FOV	Field of View
FY	Fiscal Year (federal FY begins each October)
FYDP	Future Years Defense Plan (funding plan by PE for 8 years, FY-1 through FY+6)
GATM	Global Air Traffic Management
Gbps	Gigabits per second, 10^9 bps
GB, or Gby	Gigabyte, 10^9 bytes
Glass	Colloquial term for an AMLCD flat panel display made with glass substrates
Glass Cockpit	Instrument panel filled with electronic displays made from glass (esp. CRT, AMLCD)
GLV	Grating Light Valve (MEMS miniature display device; modulates by diffraction of laser)
GPS	Geo Positioning Satellite (navigation system)
HAC	House Appropriations Committee (House funding cmte for on-going & new govnt Pgms)
HAC-Defense	HAC Defense Subcommittee (House funding subcmte for on-going&new DoD Pgms)
HASC	House Armed Services Committee (House authorizing cmte for <i>new</i> Programs in DoD)
HDTV	High Definition TeleVision
HF	High Frequency, Human Factors
HHIR	Hand Held InfraRed (camera)
HHTI	Hand Held Thermal Imager
HIDSS	Head-mounted Information Display and Sensor System (part of RAH-66 program)
HMPx	Hecto-Megapixel, 100 Mpx, 10^8 pixels
HRP	High Resolution Process (IBM AMLCD with data lines and ITO aligned vertically)
Hz	Cycles per second; or, for a display device, image frames per second
ILED	Inorganic Light Emitting Diode
IT, IIT, I ² T	Image Intensifier Tube (integrated sensor-amplifier-display device in LLLTV or NVG); For NVG: transforms NIR image into ~ 5 to 7 Mpx green image over 30-40° FOV; comprises a (a) cathode, (b) MCP, (c) phosphor and (d) fiber-optic twist to (a) convert a VIS or NIR image to electrons ($I_{VIS,NIR} \rightarrow J_{cathode}$), (b) spatially sample $J_{cathode}$ into ~7 M microchannels and amplify each to produce $J_{anode} = \sim 10^5 J_{cathode}$, (c) convert J_{anode} into visable green image ($J_{anode} \rightarrow I_{green}$) and (d) invert the image and de-sample to ~5 Mpx.
Illuminance	Light incident on (arriving at) a surface, standard unit = $lm\ m^{-2} = lux$ (lx); Archaic unit = $lm\ ft^{-2} = foot-candle$ (fc), where 1 fc = 10.7639 lx .
IP	Intellectual Property, Industrial Production
IPNVG	Improved PNVG (to include embedded uAMOLED display for symbology, FLIR image)

IPO	Initial Public Offering
IPS	In-Plane Switching (AMLCD /w both electrodes on same substrate rather than one each)
ITO	Indium Tin Oxide (transparent conductor material used in image area of a display)
JDL	Joint Director of Laboratories, Office of the Director of Defense Research & Engineering
JHMCS	Joint Helmet Mounted Cueing System (for F-14, F-16, F-18)
JSF	Joint Strike Fighter, now designated F-35 (for USAF, USN, USMC, UK, other FMS)
JSTARS	Joint Surveillance Targeting and Reconnaissance System (e.g. E-8C JSTARS)
L	Symbol used for luminance
LANL	Los Alamos National Laboratory
LCC	Life Cycle Cost
LC	Liquid Crystal (modulates polarization of transmitted or reflected light)
LCD	Liquid Crystal Display (voltage-driven light-valve display device)
LCOS	Liquid Crystal On Silicon (short for "reflective miniature AMLCD on silicon substrate")
LED	Light Emitting Diode (typically refers to ILED, but also may refer to OLED)
Light	Electromagnetic energy with wavelength, λ , in the range $300 \leq \lambda \leq 30,000$ nm)
Light Engine	Image generation unit (microdisplays, electronics, optics, source) for a projection display
LLNL	Lawrence Livermore National Laboratory
LRU	Line Replaceable Unit (of a DoD system)
LTWS	Light Thermal Weapon Sight
lumen	Standard unit of luminous flux $\equiv 1$ cd sr
Luminance	Light leaving a surface (reflection, emission, both); standard unit = $1 \text{ cd m}^{-2} = 1 \text{ nit (nt)}$; archaic unit = foot-Lambert (fL), where $1 \text{ fL} = 3.42626 \text{ cd m}^{-2}$
LW	Land Warrior (Army program which includes a uAMOLED-based HMD on each soldier)
MANTECH	Manufacturing technology
MAUG	Military Avionics Users Group (of the United States Displays Consortium)
MB, or Mby	Megabytes, 10^6 bytes
Mcell	Mega-cells, 10^6 cells, of a multi-dimensional mesh model for a physics calculation
MCP	Microchannel plate (spatially samples cathode current I_{cathode} and amplifies it 10^5 to I_{anode})
MCR	Mission capable rate (e.g. fraction of a vehicle fleet available for service at a given time)
MEMS	Micro-Electro-Mechanical System
Metrics for Display Applications	
- Avionics	\$/lb
- Dismounted	lb (includes power sources like batteries, fuel cell, etc.)
- Simulators	HMpx
- Cmd Ctrs	HMpx, Tbps
- All	Battlefield effects, combat effectiveness, target accuracy, OADA loop time

MFD	Multi-Function Display
MIM	Metal-insulator-metal diode (one type of device used to fabricate AM in FPDs)
Miniature Display	Device that produces miniature image that is magnified before viewing (direct or virtual) Includes 1-9 in. diagonal uCRTs in projection TV that generates a large screen view Includes 0.25-3 in. diagonal uFPDs
MIR	Mid-Infra-Red (1-2nm and 3-5 nm portions of the electromagnetic spectrum)
MOEMS	Micro-Opto-Electro-Mechanical System (aka MEMS)
MP	Mobile Phone (syn. Cell Phone)
Mpoly	Megapolygon, 10^6 polygons (usually triangles)
MPx	Megapixel, 10^6 pixels
mrاد	Milliradian, 1 mrad = 3.44 arc min
MS1553B	Military Standard 1553B, 1 Mbps (commercial equivalent: SAE AS15531)
MSTN	Monochrome STN
MTF	Modulation Transfer Function, intensity of signal (electrical, photonic) transmitted by a device as a function of frequency (temporal or spatial)
NB	NoteBook (mobile PC with FPD; mass market enabled by invention of AM TFT LCD)
NAVSEA	Naval Sea Systems Command
NEMS	Nano-Electro-Mechanical System
nit, nt	Unit of luminance equal to 1 cd m ⁻²
NIR	Near Infra-Red (EM energy with wavelength, λ , in range $600 \leq \lambda \leq 800$ -1,200 nm)
NMOS	Negatively doped metal oxide semiconductor (transistors)
NRL	Naval Research Laboratory
NSC	Natick Soldier Center (component of U.S. Army RDECOM)
NSSN	New Attack Submarine
NTSC	National Technical Standards Cmte, US TV broadcast standard (525 lines, 336 spots/line)
NVG	Night Vision Goggle
NVESD	Night Vision and Electronics Sensors Directorate, part of CERDEC (see RDECOM)
OADA	Observe, Assess, Decide, Act
OEM	Original Equipment Manufacturer (integrates display component into consumer product)
Offset	Component manufacturing steps done in one country for its system purchase in another
OFW	Objective Force Warrior (future Army program to begin system development in 2008)
OLED	Organic Light Emitting Device (current-driven display device)
OTW	Out-The-Window (view out of a cockpit, flight deck, control tower)
Panel	Generic term used for a FPD, and most often to an AM TFT LCD in particular
PBR	President's Budget Request (to Congress each Feb for FY beginning in Oct)

PC	Personal Computer
PDA	Personal Digital Assistant
PDP	Plasma Display Panel (current driven display device)
PE	Program Element (budget line; e.g. element of DoD RDT&E Program)
PEM	Program Element Monitor (service person who manages communications in DC on PE)
PHOLED	Phosphorescent OLED, material with quantum efficiency 4X fluorescent OLED material
Pixel	Picture element (smallest part of a display with properties of full device; smallest spatial portion of a sampled representation of an image (via computer or sensor; measure of capability of display (sensor, computer) to show (record, generate) an image)
Pixel Density	Pixels per distance or area; e.g. pixels per inch (ppi) or square inch (ppsi)
pka	previously known as
PLED	Polymer Light Emitting Diode/Device/Display
Plus-up	Congressional increase to a Program in the PBR directing administration to spend more
PM	Program Manager (of weapon system)
PMFD	Primary Multi-Function Display
PMOS	Positively-doped metal oxide semiconductor (transistors)
POD	Polyplanar Optic Display (commercial version: SCRAMscreen™, SCRAM Tech. Inc.)
POM	Program Objective Memorandum (DoD goals stmt for 6 yrs, for e.g. RDT&E Program); POM begins in an even year; planning begins two years before the first year of POM
POMyy	POM period beginning in Fiscal Year 20yy, where 20yy is an even year.
Pork	Add or Plus-up to PBR specifying an effort to be executed in a particular state or district
PNVG	Panoramic Night Vision Goggle (90 x 38° goggle using four image intensifier tubes)
ppi	Pixels per inch
printing	Mechanical display whose image is not changeable during life of substrate (usu. paper)
Product Grades:	
- Civil	Product design based only on needs of non-military users in
- Commercial	Money made producing products for sale in any viable market, civil or military
- Military	Product design specifically based on needs of combat users
- COTS	Commercial-Off-The-Shelf, means non-recurring design and engineering costs have been incurred by an earlier military or a civil product investment program
- Custom	Special design fabricated in an economically viable, market-driven manufacturing facility
Projection	Direct-view display comprising a light engine, optical magnification system, and screen
QDR	Quadrennial Defense Review
RAH-66	Reconnaissance Attack Helicopter, nickname: Comanche
RDECOM	U.S. Army Research, Development and Engineering Command
Reliance	Process by which various separate DoD service and agency S&T programs are de-conflicted to remove unnecessary duplication and to identify opportunities for synergy

Research

- Basic New concepts, phenomena; 6.1; TRL 1-2 (of 9, see TRL definitions below)
- Exploratory New materials, applications, devices; 6.2; TRL 3-5 (of 9, see TRL definitions below)

Resolution Conventions

- spatial area "n pixels" means image representation includes n spatial samples (actual or computed)
"n x m pixels" means image is created in format of "n-horz. by m-vert. pixels"
- spatial density "n ppi" means n pixels per inch, "n cy/degree" means ≥ 2 pixels per angular degree
- grayscale "n bits" means image representation includes 2^n greylevels per pixel
- temporal "n Hz" means image representation includes n updates per second

Resolution Formats:

- PDA1 160 x 160 (25,600 pixels), 1:1 aspect ratio
- qCIF+ 220 x 176 (38,720 pixels), 5:4 aspect ratio
- qVGA 320 x 240 (76,800 pixels), 4:3 aspect ratio (NTSC)
- PDA2 320 x 320 (102,400 pixels), 1:1 aspect ratio
- VGA 640 x 480 (307,200 pixels), 4:3 aspect ratio
- DVD 720 x 480 (345,600 pixels), 3:2 aspect ratio
- WVGA 800 x 480 (384,000 pixels), 5:3 aspect ratio
- SVGA 800 x 600 (480,000 pixels), 4:3 aspect ratio
- UWXGA 1024 x 512 (524,288 pixels), 2:1 aspect ratio
- WSVGA 1280 x 600 (768,000 pixels); 32:15 aspect ratio
- XGA 1024 x 768 (786,432 pixels), 4:3 aspect ratio
- WXGA 1152 x 768 (884,736 pixels), 3:2 aspect ratio
- WXGA+ 1280 x 768 (983,040 pixels), 5:3 aspect ratio
- QVGA 1280 x 960 (1,228,800 pixels), 4:3 aspect ratio
- SXGA 1280 x 1024 (1,310,720 pixels), 5:4 aspect ratio
- SXGA+ 1400 x 1050 (1,470,000 pixels), 4:3 aspect ratio
- UXGA 1600 x 1200 (1,920,000 pixels), 4:3 aspect ratio (engineering workstations)
- HDTV2 1280 x 720 (921,600 pixels), 16:9 aspect ratio (low-end HDTV), products exist
- HDTV4 1980 x 1024 (2,027,520 pixels), 16:9 aspect ratio (high-end HDTV), technology exists
- QXGA 2048 x 1536 (3,145,728 pixels), 4:3 aspect ratio
- QSXGA 2560 x 2048 (5,242,880 pixels), 5:4 aspect ratio
- QUXGA 3200 x 2400 (7,680,000 pixels), 4:3 aspect ratio
- QUXGAW 3840 x 2400 (9,216,000 pixels), 16:10 aspect ratio (IBM T221 monitor), defines frontier
- 16SXGA 5120 x 4096 (20,971,520 pixels), 5:4 aspect ratio (goal of on-going AFRL S&T program)

ROI Return on Investment

ROW Rest of World

RP Rear Projection

R&D Research and Development (S&T plus engineering development, systems support)

S&T Science and Technology (basic and applied research, advanced development, mantech)

ST Special Tactics

S and T Strategic and Tactical (systems)

SAR Synthetic Aperture Radar

SAC Senate Appropriations Committee (Senate funding cmte for on-going & new govt Pgms)

SAC-Defense SAC Defense Subcommittee (Senate funding subcmte for on-going & new DoD Pgms)

Sampling	
- Spatial	Pixels
- Color	Intensity grayscale and CIE coordinate
- Temporal	Units per second, units equal e.g. frames of an image sequence (computed or sensed)
SASC	Senate Armed Services Committee (Senate authorizing cmte for new Programs in DoD)
Screen	
- Generic	Direct-view (DV) image created by any type of display technology
- Front	Reflective surface, often engineered, creating DV image for eye (from FP display)
- Rear	Transmissive optical layer, typically engineered, creating DV image for eye (RP display)
SCRAMscreen	POD, Polyplanar Optic Screen, invented by Brookhaven National Laboratory, commercialized by SCRAM Technology, Inc. for rear projection TV application
S&C	Space & Communications
SEP	System Enhancement Program (e.g. Abrams M1A2 SEP, Bradley M2A3 SEP)
SH21	Strike Helmet 21 (advanced HMD system for fighter pilots)
Size Conventions	
	"n in." format means "n inch diagonal image size of a display with a rectangular shape"
	"n in. diameter" means "n inch diameter image size of a display with a circular shape"
	"n x m in." format means "n-in. horz. by m-in. vert. image size, rectangular shape"
SM&P	Supplier Management and Procurement
SNL	Sandia National Laboratories
SNR	Signal to Noise Ratio
SOCOM	Special Operations Command (one of the nine DoD Combatant Commands)
SPAWAR	Space and Naval Warfare Systems Center, U.S. Navy
SSLP	Solid State Laser Projection (Display)
STN	Super-twisted neumatic LCD (has 270° LC rotation from one substrate to other at zero V)
Subpixel	Separately addressable component of a pixel (comprising aR x bG x cB subpixels)
Substrate	
- Glass	Standard material for most displays of all technologies, types and sizes
- Quartz	Research only; too expensive for production
- Silicon	Used for reflective micro-LCD (LCOS), emissive micro-OLED; too expensive for larger
- Plastic	Being explored to reduce weight and cost of flat panel displays based on LCD, OLED
- Steel	Being explored to reduce weight and cost of flat panel displays based on LCD, OLED
TAC	Tactical Air Combat, Terminal Attack Center
TAD	Tactical Area Defense (or Direction, or Directive)
TACOM	Tank Automotive & Armament Command, U.S. Army
Technology Maturity (exit criteria for an S&T investment)	
- R	Research and Development Result
- P	Prototype / Demonstration
- A	Affordability Effort & ProducibilityQualification
TB, TBy	Terabyte, 10 ¹² bytes

TED	Transparent Emissive Display; 3DTL term for its spray-on screen (see also TOLED)
TFEL	Thin Film Electroluminescent (display technology)
TFT	Thin Film Transistor (yields less than 100% produce clearly visible display defects)
- AMLCD	Has one TFT per addressable subpixel; e.g. #TFTs = #pixels x 3 x 1
- AMOLED	Has 2-6 TFT per addressable subpixel; e.g. #TFTs = #pixels x 3 x 2-6
TFTLCD	AMLCD with AM implemented with TFTs
Title III	See Defense Production Act (DPA)
TMDS	Transition-Minimized Differential Signaling
TN	Twisted Neumatic LCD (has 90° LC rotation from one substrate to other at zero V)
TOC	Tactical Operations Center
TOLED	Transparent OLED; Princeton term for its flexible emissive display (see also TED)
TRADOC	Training and Doctrine Command, U.S. Army
TRL	Technology Readiness Level – nine progressive milestones for an R&D investment
TRL-1	Basic principles observed and reported (6.1 basic research)
TRL-2	Technology concept and/or application formulated (6.2 exploratory research)
TRL-3	Analytical & experimental critical function / proof-of-concept (6.2 exploratory research)
TRL-4	Component breadboard validation in a laboratory environment (6.2 exploratory research)
TRL-5	Component breadboard validation in a relevant environment (6.3 advanced development)
TRL-6	Subsystem model or prototype demonstration in a relevant environment (6.3 adv. devmt)
TRL-7	System prototype demonstrator in an operational environment (6.3 advanced dvmt)
TRL-8	System qualified in combat environment (6.4 engineering development)
TRL-9	System proven in combat (6.4 engineering development)
TTL	Transistor-to-Transistor Logic
TV	Television
uAMLCD	Miniature- or Micro-AMLCD (for application in near eye and projection applications)
uAMOLED	Miniature- or Micro-AMOLED (for application in near-eye applications)
uCRT	Miniature- or Micro-CRT
uD	Miniature- or Micro-Display
uFPD	Miniature- or Micro-FPD
USDC	United States Displays Consortium
Veridical	Perfect replica (of image or photo)
Virtual View	Image not physically located where eye perceives it to be; only one person can see image; Image created via an optical system, often integrated with a CCD and miniature display Examples: camera view-finders, HMD systems
Voxel	Volumetric Picture Element (smallest element of a direct-view true 3D display)
Wi-Fi	Wireless standard series IEEE 802.11x, 11 or 55 Mbps on 2.4 (b, g) or 5 GHz (a) carrier)

Wi-Video	Wireless standard series IEEE 802.15.3
Wireless	IEEE 801.11x (Wi-Fi), IEEE802.15.1 (Bluetooth), IEEE802.15.3 (Wi-Video)
Wirelink	MS1553B, IEEE1394 (FireWire)
WR-ALC	Warner-Robins Air Logistics Center
VIS	Visible light (electromagnetic energy with wavelength of $400 \leq \lambda \leq 700$ nm)
VRD	Virtual Retinal Display